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Discrimination of sweet-fat ingredients in people with weight- and eating-related problems using a signal detection theory

David Garcia-Burgos[1] | Fabienne Andres[1] | Stephan Trier[2] | Claus Vögele[3] | Simone Munsch[1]

[1]Department of Psychology, University of Fribourg, Fribourg, Switzerland

[2]Klinik Aadorf, Aadorf, Switzerland

[3]Institute for Health and Behaviour, Department of Behavioural and Cognitive Sciences, University of Luxembourg, Luxembourg, Luxembourg

Correspondence
David Garcia-Burgos, Institute of Neurosciences, University of Granada, Avda. del Conocimiento s/n, 18100 Armilla, Granada, Spain.
Email: davidgb@ugr.es

Present address
David Garcia-Burgos, Department of Psychobiology, Institute of Neurosciences, University of Granada, Granada, Spain.

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Abstract

Individuals with impaired gustatory perception may have altered ingestive behaviors, which contribute to unhealthy weight status and disordered eating. Whether and to what extent weight status or eating symptomatology depend on flavor perception is still a controversial issue. Thus, the ability to discriminate among different levels of sweetness/fat content was compared in three studies using two-alternative forced-choice tasks and the standardized metrics of signal detection theory (SDT). In Study 1, three body mass index groups were included: underweight, healthy normal weight, and overweight. In Study 2, volunteers were currently-ill and recovered (anorexia/bulimia nervosa) patients, and two age- and weight-matched control groups. In Study 3, SDT metrics of both populations were compared. Results showed that SDT measures identified difficulties of underweight individuals to discriminate fat levels in sugary products, while patients with eating disorders exhibited outstanding discrimination of fat ingredients. Judgment biases were also detected in both populations. This highlights importance of using SDT methodology in flavor perception research in people with weight−/eating-related problems.

Practical Applications

This paper may serve as a starting point for the establishment of a consensual methodology in the field of flavor perception using the SDT approach. Especially in populations with eating- and weight-related problems, it is both of considerable interest and a necessity to establish and promote standard metrics to provide more consistent and comparable results on the perception of sweet and fat inputs. On the one hand, SDT may be a valuable tool to deal with current methodological limitations and heterogeneity in methods used across studies. On the other, this should facilitate further study of the relationship between oral sensations and unhealthy eating and drinking behaviors to improve individuals' nutritional status and quality of life.

** Claus Vögele and Simone Munsch shared last authorship.

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1 | INTRODUCTION

Weight-related problems and eating disorders represent two pervasive conditions, especially in Western societies. In the general population, worldwide estimations point out an age-standardized global prevalence of underweight and obesity of 8.8% and 10.8%, respectively, in men and 9.7% and 14.9% in women (NCD Risk Factor Collaboration, 2016). Underweight and obesity have been associated with increased mortality and constitute risk factors for cardiovascular and musculoskeletal diseases, as well as functional capacity and health-related quality of life (Flegal, Graubard, Williamson, & Gail, 2005; National Task Force on the Prevention and Treatment of Obesity, 2000). Eating disorders such as anorexia nervosa (AN) or bulimia nervosa (BN), which are common in adolescence and young adulthood and have a lifetime prevalence of up to 8.4% for women and 2.2% for men, significantly impair physical health, psychosocial functioning, and quality of life (American Psychiatric Association [APA], 2013).

Several mechanisms have been suggested to play a role in both conditions, including disturbances in flavor perception (Drewnowski, 1989; Drewnowski, Halmi, Pierce, Gibbs, & Smith, 1987; Stevenson, 2007). Indeed, individuals with impaired taste function seem to be more likely to be affected by altered eating behaviors that drive or exacerbate disordered eating as well as diet- and nutrition-related conditions (cf. Duffy, 2020). This may be the case for the appetitive flavors associated with calories such as sweet and fat in both categories, that is, overweight/obese and eating disorders.

Regarding people with weight-related problems, overconsumption of foods rich in added sugars and fat appears to be particularly relevant given their role as a contributing factor in weight gain (Jeffery & Harnack, 2007). Thus, there is considerable literature comparing the perception of simple primary sweet (e.g., sucrose or glucose) and fat stimuli (e.g., long-chain fatty acids; see Keast & Costanzo, 2015), as well as sweetened mixtures containing fat (e.g., sweet dairy products), between individuals with high body mass index (BMI) and those of normal weight (for recent reviews see Brondel et al., 2022; Cox, Hendrie, & Carty, 2016; Heinze, Preissl, Fritsche, & Frank, 2015; Khan, Keast, & Khan, 2020; Ribeiro & Oliveira-Maia, 2021).

Unfortunately, evidence to date remains inconclusive on the association between body weight status and sensory perception of sweet taste. While some studies have found support for a negative relationship (Dias et al., 2015; Proserpio, Laureati, Bertoli, Battezzati, & Pagliarini, 2016; Sartor et al., 2011; Skrandies & Zschieschang, 2015), other studies have not (Donaldson, Bennett, Baic, & Melichar, 2009; Frijters & Rasmussen-Conrad, 1982; Grinker, 1978; Martinez-Cordero, Malacara-Hernandez, & Martinez-Cordero, 2015) or have even reported a rather positive association (Drewnowski, Brunzell, Sande, Iverius, & Greenwood, 1985; Hardikar, Höchenberger, Villringer, & Ohla, 2017; Pasquet, Laure Frelut, Simmen, Marcel Hladik, & Monneuse, 2007). It is also surprising that, to the best of our knowledge, no studies have examined sweet/fat perception in non-clinical underweight people. Similar heterogeneity has been reported in the case of sensory fat perception.[1] Some authors have observed BMI-dependent differences where individuals with healthy normal weight seem to be better at detecting small differences in fatty acids compared to individuals with higher BMIs (Stewart et al., 2010) and an attenuated perception in overweight/obese people (Chevrot et al., 2014; Stewart, Newman, & Keast, 2011; Stewart, Seimon, et al., 2011). Notwithstanding, others have shown no BMI-dependent effects, even when examining Pima Indians, a population prone to obesity (Keast, Azzopardi, Newman, & Haryono, 2014; Mattes, 2011; Salbe, DelParigi, Pratley, Drewnowski, & Tataranni, 2004; Tucker et al., 2017).

Over the past decades, an increasing number of studies have also sought to determine perception of sweet-fat flavors in eating disorders to the extent that they usually avoid these particularly appealing foods (Drewnowski, 1997). However, findings have likewise been contradictory (for a recent review see Chao, Roy, Franks, & Joseph, 2020). For instance, decreased or altered taste function in patients suffering from BN and AN has been observed relative to healthy controls (Aschenbrenner, Scholze, Joraschky, & Hummel, 2008; Casper, Kirschner, Sandstead, Jacob, & Davis, 1980; Dazzi, Nitto, Zambetti, Loriedo, & Ciofalo, 2013; Drewnowski et al., 1987; Nakai, Kinoshita, Koh, Tsujii, & Tsukada, 1987; Rodin, Bartoshuk, Peterson, & Schank, 1990). In contrast, other studies have not found such abnormalities or differences (Dazzi et al., 2013; V. di Costanzo et al., 1998; Drewnowski et al., 1987; Goldzak-Kunik, Friedman, Spitz, Sandler, & Leshem, 2012; Vocks, Herpertz, Rosenberger, Senf, & Gizewski, 2011). Interestingly, when gustatory alterations were detected, they were partially reversible after psychological interventions (Goldzak-Kunik et al., 2012; Nozoe et al., 1996) or weight restoration (Aschenbrenner et al., 2008). Moreover, the fact that AN patients respond differently to swallowed and to expectorated sugar solutions suggests that these abnormal responses might be driven by fear of calories rather than by taste per se (Eiber, Berlin, de Brettes, Foulon, & Guelfi, 2002).

An important number of these inconsistent and contradictory results in people suffering from eating- and weight-related problems may be explained by the different approaches to measurement of flavor perception and the lack of standardized methodology (Chao et al., 2020; Donaldson et al., 2009). Indeed, diversity in methods (including design, sample size and procedure) and results has led to considerable difficulties in interpreting the available literature regarding both conditions (Bartoshuk, Duffy, Hayes, Moskowitz, & Snyder, 2006; Chao et al., 2020; Kinnaird, Stewart, & Tchanturia, 2018; Leland et al., 2021). For instance, classical psychophysical measures and self-reported scales/questionnaires have been called into question because they do not provide accurate measures of sensory sensitivity to the extent that judgments are not free of errors and biases. This emphasizes the need for further research using consensual methodology (cf. Ribeiro & Oliveira-Maia, 2021).

Interestingly, signal detection theory (SDT; Macmillan, 2002) can address some of the traditional limitations and offer a specific, quantifiable analysis of flavor discrimination. In agreement with the idea that the perception of a flavor is not in the food but is created in the brain (Small, 2012), this methodology allows to understand the information processing that takes place in the brain during tasting. To do so, it separates the sensory process (in which the physical stimulus information is transformed into neural representation) from the decision process (i.e., the rule that determines which response to give based on the output of the sensory process) and the response bias (i.e., the tendency to answer in one specific way unrelated to the quality of the stimuli) when making a judgment.

A remarkable feature is that SDT parameters can be estimated from different discrimination methods and then compared with one another, even if they have been obtained from different studies (Bi, 2008; Hautus, Macmillan, & Creelman, 2021). Also, use of these standardized metrics makes it possible to determine whether the sensitivity/bias of different groups is particularly large, as well as to be evaluated against one another as while the discrimination/sensitivity index (namely, d') typically ranges from 0.5 to 2.5, corresponding to 60% and 90% accuracy, response bias typically ranges from −2.33 to 2.33 (Macmillan & Creelman, 2005). Finally, according to SDT, sources of variations are assumed to come from decision factors operating within the central nervous system, such as the psychological condition of a subject at the time of response. Thus, it may account for variations in judgment of the same gustatory stimulus by the same individual on different occasions, which may be incorrectly interpreted as contradictory results in sensory discrimination. Unfortunately, application of the SDT approach so far remains largely unexplored for populations with weight-related problems and eating disorder.

Consequently, using the standardized metrics of SDT, the objectives of this research were to examine the ability to discriminate among sweet-fat flavors and to test whether such differences in discrimination ability have an impact on actual intake behavior in underweight (UW), normal weight (NW) and overweight (OW) individuals without mental disorders (Study 1), as well as in patients suffering from AN and BN at different stages of the disorder (currently ill vs. recovered) (Study 2). The fact that flavor perception, BMI, and eating disorders are related is not new. Aschenbrenner et al. (2008) have reported that in AN, overall taste scores correlated with BMI. Also, the differences between subtypes of AN in the sweet taste detection threshold disappeared when BMI was introduced as a covariate in Eiber et al.'s (2002) study. What remains to be explored is how flavor discrimination differs between patients with eating disorders and individuals with weight problems. Thus, an additional objective was to compare flavor discrimination ability between both populations (Study 3).

In terms of hypotheses, based on studies including sufficiently large sample sizes of subjects of both sexes with a wide range of BMI (e.g., BMI of up to 50, $n = 3{,}740$; Bartoshuk et al., 2006; Stewart, Newman, & Keast, 2011; Stewart, Seimon, et al., 2011), we hypothesized that higher values of BMI should be associated with lower ability to discriminate sugar-fat ingredients once variations due to bias were minimized (Hypothesis 1). On the other hand, if perceptual disturbances in eating disorders are related to biased cognitions about gaining weight rather than to actual gustatory deficits or BMI (Drewnowski, 1993; Eiber et al., 2002), then currently ill AN and BN patients should show no differences in their ability to discriminate sweet-fat tastes compared both to recovered patients and to underweight and normal-weight controls (Hypothesis 2); they should also exhibit higher response bias scores, and even more so during a swallowing vis-à-vis a sip-and-spit protocol (Hypothesis 3). Finally, if increasing sweet/fat intake causes decreased taste sensitivity (Brondel et al., 2022; Khan et al., 2020), higher flavor discrimination should be observed in patients with eating disorders that avoid dietary sweet and fat foods compared to overweight people (Hypothesis 4).

2 | MATERIALS AND METHODS

The present research was conducted in the form of three studies. All procedures were approved by the ethics committee of the leading center at the University of Fribourg (CER-VD No. 30/14 and CER-VD No. 2016-02150) and in the cantons of collaborating clinics in Switzerland, as well as the Ethics Review Panel of the University of Luxembourg. Procedures were conducted in accordance with Good Clinical Practice guidelines. Participants provided written informed consents.

2.1 | Study 1: Discrimination in people with weight-related problems

2.1.1 | Participants

A total of 59 volunteers of both sexes were recruited using flyers and advertisements and then classified into 3 BMI categories based on the World Health Organization standards: UW (BMI < 18.5 kg/m^2), healthy NW (BMI 18.5–24.9 kg/m^2), and OW (BMI 25–29.9 kg/m^2). The final sample distribution was as follows: $N_{\mathrm{UW}} = 20$, $N_{\mathrm{NW}} = 20$, and $N_{\mathrm{OW}} = 19$ (Figure 1). The inclusion criteria were reading and understanding the study and its procedures and age between 18 and 35. The exclusion criteria were food allergies; sensorial deficit; salivary, metabolic and/or otorhinolaryngologic disorders; gluten/milk lactose intolerance or aversion; pregnancy or lactation where appropriate; current or past history of eating disorders; and smoking. In order to characterize the sample, demographic, health, physiological and psychological variables were used (Table 1) via the following questionnaires: Health Questionnaire about current diet, health condition, eating disorders, food allergies or aversions; Restraint Scale (RS; Herman & Mack, 1975); Three Factor Eating Questionnaire (TFEQ; Karlsson, Persson, Sjöström, & Sullivan, 2000); and Behavioral Inhibition/Activation System Scale (BIS-BAS; Carver & White, 1994) to assess dispositional sensitivities underlying behavior and affective responses toward goals.

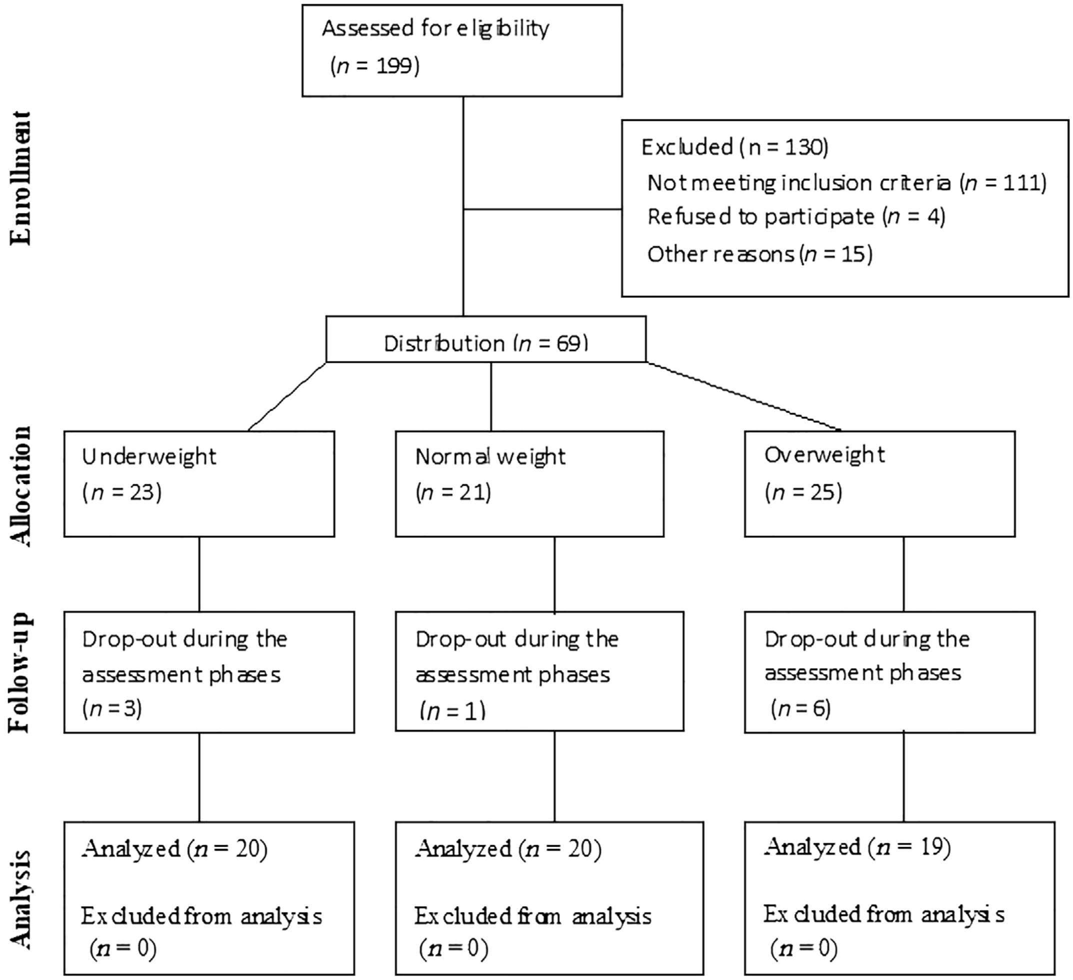


FIGURE 1 CONSORT flow diagram of recruitment and progress throughout Study 1: people with weight-related problems

TABLE 1 Baseline characteristics of study participants for underweight (UW), healthy normal weight (NW), and overweight (OW) groups

Characteristic	UW ($n = 20$)	NW ($n = 20$)	OW ($n = 19$)	*p* value
Age (years)	24.3 (5.56)	22.4 (6.43)	29.7 (9.49)	
BMI (kg/m^2)	17.62 (0.83)	21.28 (1.82)	28.89 (2.85)	
Sex (female)	18	18	14	
Current hunger (score)	3.42 (2.52)^a	5.80 (3.07)^b	4.94 (3.01)	.05
Current thirst (score)	4.47 (2.52)^a	6.67 (2.10)^b	6.94 (2.74)^b	.01
Food familiarity (score)	89.93 (6.10)	90.45 (4.63)	91.34 (6.21)	.10
BAS$_{\text{Drive}}$	9.63 (1.67)	9.56 (1.55)	10.65 (1.84)	.13
BAS$_{\text{Fun seeking}}$	8.63 (2.16)^a	12.00 (2.42)^b	10.12 (2.32)^a	.001
BAS$_{\text{Reward}}$	10.00 (3.35)^a	17.19 (1.52)^b	12.82 (4.88)^a	.001
BIS	18.75 (5.27)	20.06 (2.21)	17.59 (3.36)	.19
Restraint scale (score)	12.13 (2.28)^a	21.13 (4.56)^b	26.53 (4.42)^c	.001
TFEQ$_{\text{Cognitive restraint}}$	7.75 (3.02)^a	13.06 (3.99)^a	15.76 (3.35)^b	.001
TFEQ$_{\text{Uncontrolled eating}}$	15.06 (3.71)^a	19.06 (4.43)^a	23.35 (5.96)^b	.001
TFEQ$_{\text{Emotional eating}}$	4.50 (3.18)^a	7.13 (2.22)^b	6.71 (2.93)^a	.02
TFEQ$_{\text{Total}}$	27.31 (6.64)^a	39.25 (7.92)^b	45.82 (8.37)^c	.001

Note: *p* values were generated from ANOVAs. Values with different superscripts represent means that are statistically different among groups (columns) after post-hoc analysis ($p \leq .05$). Mean values (with standard deviations).

Abbreviations: BAS, Behavioral Approach System scale; BMI, body mass index; BIS, Behavioral Inhibition System scale; TFEQ, Three Factor Eating Questionnaire.

2.1.2 | Tasting samples

Two milk solutions containing different levels of dietary fat, that is, whole milk (3.5% fat, Denner, Switzerland) or reduced-fat milk (1.5% fat, Denner, Switzerland), were used in combination with two sweeteners, that is, 5% sugar (wt/vol; Cristal 100, Zuckersticks) or 0.08% stevia (wt/vol; Zueristevia 200). These milk solutions were selected because they provide a well-characterized system to study sweet–fat interactions (Hayes & Duffy, 2007). The concentrations of sucrose and stevia were chosen because of their ecological validity in real world consumption. Stevia is a natural sweetener and sugar substitute derived from the leaves of the plant species *Stevia rebaudiana*. Sucrose concentration at 5% was the sweeter stimulus as according to the product manufacturer (www.migros.ch), 0.08% stevia is as sweet as 4% sugar. This was confirmed by our pilot study ($n = 10$; data not shown). Sugar and stevia were also used to the extent that comparisons between both sweeteners have not revealed significant differences in sweetness intensity, detection, and recognition thresholds between normal weight (BMI range: 18.5–24.9) and overweight/obese participants (BMI range: 25.0–32.9) (Low, Lacy, McBride, & Keast, 2016). The samples were prepared at the beginning of the laboratory session and presented at room temperature in 200 ml plastic cups (containing 100 ml of each milk sample) with codes.

2.1.3 | Two-alternative forced choice task and intake

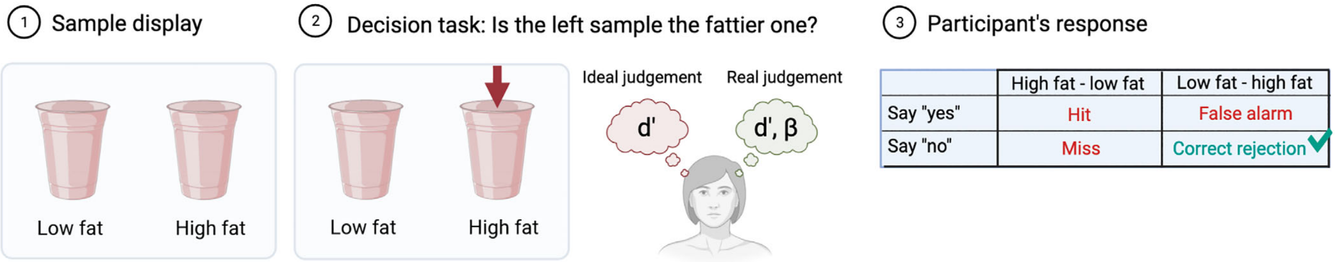
The two-alternative forced choice (2AFC) discrimination task is a ubiquitous procedure for measuring perception that provides a higher level of power for small differences and low levels of response bias (Hautus, Van Hout, & Lee, 2009). Unlike detection or recognition, a discrimination task has alternative stimuli, one of which is designated as the reference and the participant is asked only to distinguish between the reference and another stimulus. In our study, two samples (alternatives) under consideration were presented together for each test (Figure 2), with four possible pairs: low or high sweetness combined with low or high fat. Under a sip-and-spit protocol, participants were asked to state whether the sweeter or the fattier sample was placed on the left side. A total of 24 pairs for each subject (8 pairs per block) were tested to obtain: (1) the discriminability/sensitivity index (*d*′) by examining judgments to samples that vary in the attribute of interest (e.g., low versus high sweetness) when other attributes remain unchanged (e.g., same level of fat in both samples of the pair), and vice versa, by examining how changes in other attributes (e.g., low versus high fat) affect judgment of the attribute of interest (sweetness) while this remains constant (known as the mixture effect; cf. Hayes & Duffy, 2007); and (2) the response bias index as a tendency to favor one answer over another during flavor discrimination. The order of presentation of flavor samples was counterbalanced between subjects and reversed across sessions to control for taste fatigue, satiety, and learning effects. The 2AFC task was conducted using SIPM™ software (Sussex Ingestion Pattern Monitoring, version 2.0.11).

2.1.4 | Procedure

Participants were contacted by e-mail and asked to confirm the inclusion and exclusion criteria. They then filled out the questionnaires using the LimeSurvey platform (www.limesurvey.org) before the experimental session in the laboratory and were asked to fast for 90 min prior to the session. The experimental session consisted of three blocks. Each one lasted about 20 minutes and included: (1) presentation of one set of images for a total time of 10 minutes to induce a similar psychological state among BMI groups; (2) rating of the level of thirst and hunger and food familiarity; (3) placing a dental cotton roll in the area of the molars during presentation of each set of pictures to control the amount of saliva as lower salivary flow has been associated with impaired oral sweet and fat detection in people with obesity (Modéer, Blomberg, Wondimu, Julihn, & Marcus, 2010); and (4) the 2AFC task. Participants completed flavor testing on the same day. The experimental session took about 70 min.

2.1.5 | Design and study outcomes

A quasi-experimental, cross-sectional study was employed. The primary outcomes were the standardized parameters from the response



	High fat - low fat	Low fat - high fat
Say "yes"	Hit	False alarm
Say "no"	Miss	Correct rejection ✓

FIGURE 2 Two-alternative forced-choice procedures. (1) In each trial the participants are presented with two samples (left and right), and (2) they are forced to make a choice according to the criterion: "Is the left sample the sweeter/fattier one?". (3) Finally, a signal detection matrix with the hits, false alarms, misses, and correct rejections is created from the participants' responses ("yes" or "no") and the order of presentation of the samples (high-low vs. low-high)

data of the 2AFC task using the SDT approach (Hautus et al., 2009): the discriminability/sensitivity index (d') and the response bias index. Secondary outcomes were the percentage of correct responses, the amount of saliva (g) measured by determining the difference in weight of the cotton roll before and after the collection period, and total intake (g) of each food sample measured by determining the difference in weight before and after the 2AFC task. Finally, the tertiary outcomes were the scores of the RS, TFEQ, and BIS-BAS questionnaires.

2.1.6 | Sample size estimation and data analysis

The initial sample size calculation was based on standard analysis of chi-square tests using the G*Power software (version 3.1.5). Assuming alpha error probability $= .05$, beta $= .2$ and medium effect size $= 0.40$, a required total sample size of 61 was necessary to ensure power $= 0.80$. In the case of SDT, the sample size may be reduced slightly as the collected d' values take into account additional sources of variance under the response bias index. Additional calculations for our 2AFC procedure recommended a sample size of at least 50 (with detection rate of correct percentage = 55% corresponding to $d' = 1$ with type I/type II error levels of 0.05/0.20).

The SDT parameters were calculated following Stanislaw and Todorov's (1999) mathematical formulae. In particular, $d' = \frac{(\mathrm{zHit} - \mathrm{zFA})}{\sqrt{2}}$, with zHit and zFA as transformations of the hit and false alarm rates to inverse z-scores. Thus, the more sensitive an individual, the larger the value of d'. Individuals unable to discriminate obtained $d' = 0$, while $d' < 0.5$ corresponded to low discrimination, d' between 0.5 and 2 indicated moderate discrimination, and $d' \geq 2$ corresponded to high discrimination. The measure of response bias was calculated as $e^{\left\{\left[(\mathrm{zFA})^2\right] - \left[(\mathrm{zHiT})^2\right]/2\right\}}$. As to response bias and the decision criteria associated with it, the neutral point is 1, while values >1 reflects a strict criterion (i.e., a higher threshold for judging that an attribute is present with a tendency to say “No, the sweeter/fattier sample is not on the left side”) and values <1 reflects a liberal criterion (i.e., tendency to say “Yes, the sweeter/fatter sample is on the left side”). Given that conventional analysis of variance (ANOVA) is not appropriate because d' data cannot be normally distributed (cf. Bi, 2008), the procedure for computing the variance as well as the statistical inference for d' data followed Bi et al.'s (Bi, 2008; Bi, Ennis, & O'Mahony, 1997) approach. We used the Z-score statistic and the T statistic with a chi-square distribution to test whether d' values of each BMI group significantly differed from zero and the comparison of multiple d's, respectively. Analogous to d', tests and multiple comparisons based on confidence intervals at a .05 significant level (95% CIs) were constructed for response bias according to Kadlec's (1999) approach.

To determine any initial differences among body weight groups, a multivariate analysis of variance (MANOVA; BMI as between factor with three levels: UW vs. NW vs. OW) on the scores of the RS, TFEQ, BIS-BAS, hunger, thirst and food familiarity questionnaires was used. Also, one unifactorial (BMI) ANOVA for amount of saliva and a mixed 3 (BMI) × 2 (high vs. low sweetness) × 2 (high vs. low fat) ANOVA on milk intake with repeated factors Sweetness and Fat were carried out. Any significant ANOVA was followed by Tukey's tests for pairwise differences among BMI groups. A chi-square test was applied to compare the percentage of correct responses among groups. Finally, Pearson's correlations were performed to test relationships between the discrimination ability for sweetness or fat and total intake. Statistical analyses were conducted with Microsoft Excel 2007 and SPSS (IBM, SPSS; Version 23.0, Chicago, IL) and p-values (ps) < .05 were considered significant in all studies.

2.2 | Study 2: Discrimination in patients with eating disorders

2.2.1 | Participants

A total of 78 female participants were recruited in Switzerland and Luxembourg (Figure 3). AN (restricting-type) and BN (without past history of AN) patients who met the criteria of the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (APA, 2013), were divided into currently ill (C) and recovered (R) patients. Thus, C-AN ($n = 10$) and C-BN ($n = 14$) patients were compared to R-AN ($n = 15$) and R-BN ($n = 9$) patients. By searching the most similar samples, we selected patients with similar age of onset and duration of the illness, and we also included two age-matched and weight-matched control groups without eating disorders: underweight control (U-CT; $n = 15$) and normal weight control (N-CT; $n = 15$) to increase the statistical power of cross-sectional analysis and control for potential confounders such as BMI. BN with previous history of AN or binge-eating/purging type of AN were excluded to enable a better differentiation between these disorders.

The general inclusion criteria were reading and understanding the study and its procedures and age between 18 and 35. Additional inclusion criteria were added depending on the group. For U-CT and N-CT, no current or past history of eating disorders and BMI < 18.5 and 18.5–24.9, respectively, were added as inclusion criteria. In the case of C-AN and C-BN, clinical diagnosis of eating disorder and whether the treatment had started reduction of the initial eating disorder pathology <30% measured by the Eating Disorder Examination Questionnaire (EDE-Q) according to Mond, Hay, Rodgers, Owen, and Beumont (2004), as well as <50% of the target weight gain for AN and <30% reduction of binge eating and compensatory episodes for BN. R-AN and R-BN did not meet all the criteria for AN or BN disorder at the time of discharge: BMI > 18 and global EDE-Q score < 2.3 (Munsch, 2014). Exclusion criteria were pregnancy or lactation; psychotic and related disorders or depressive disorders to the extent of preventing participation in the study; serious medical conditions that have an effect on eating and mood; lack of compliance with the study procedure; past bariatric surgery; allergies to the foods offered; smoking; salivary, metabolic and/or otorhinolaryngologic disorders. Demographic and clinical characteristics of the participants are shown in Table 2.

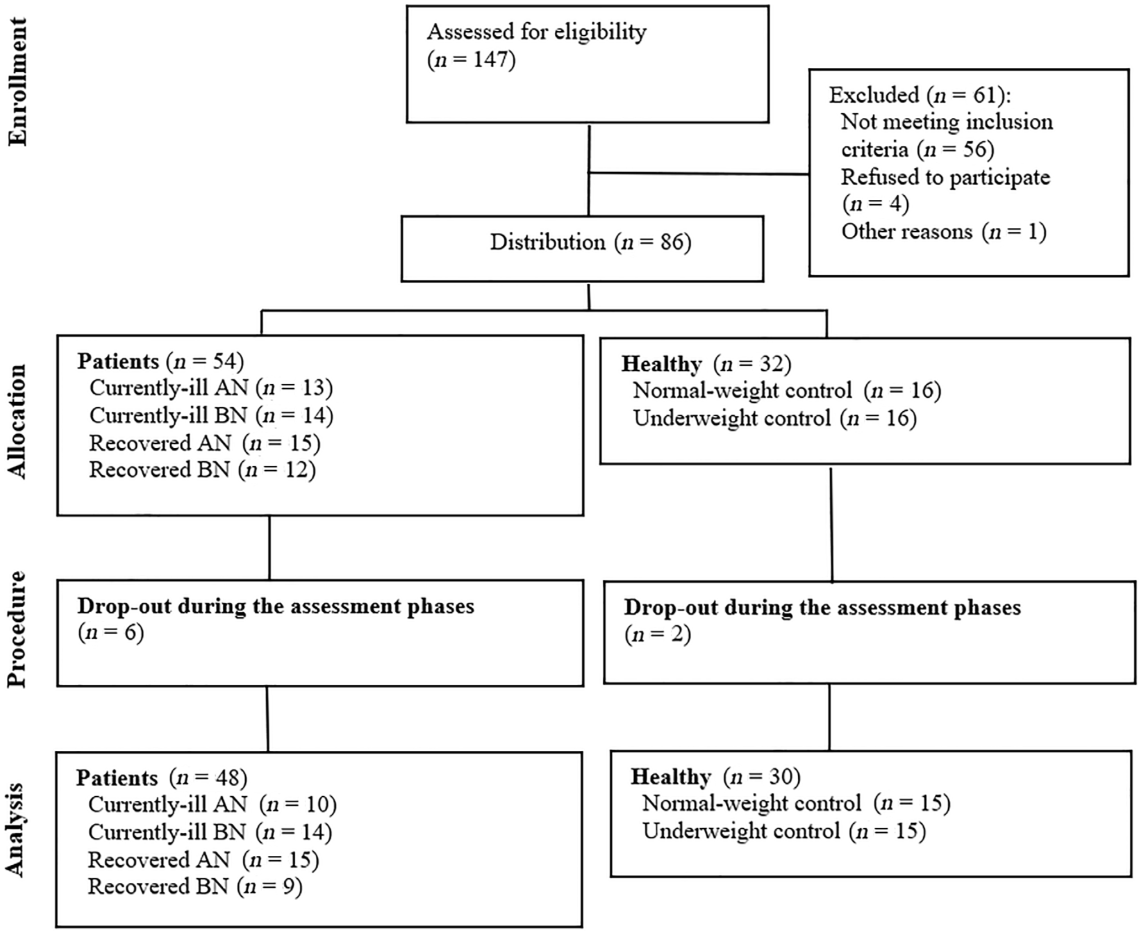


FIGURE 3 CONSORT flow diagram of recruitment and progress throughout Study 2: patients with eating disorders

TABLE 2 Baseline characteristics of study participants for currently ill anorexia nervosa (C-AN), recovered anorexia nervosa (R-AN), currently ill bulimia nervosa (C-BN), recovered bulimia nervosa (R-BN), healthy normal weight control (N-CT), and underweight control (U-CT) groups

	C-AN	R-AN	C-BN	R-BN	N-CT	U-CT	
Characteristic	(*n* = 10)	(*n* = 15)	(*n* = 14)	(*n* = 9)	(*n* = 15)	(*n* = 15)	*p* value
Age (years)	22.00 (3.12)	24.11 (4.06)	22.71 (2.23)	20.94 (2.57)	23.18 (1.52)	22.83 (2.47)	.16
BMI (kg/m^2)	16.66 (1.24)^{a}	21.02 (2.22)^{b}	22.76 (2.48)^{b,c}	23.48 (2.11)^{c}	21.25 (1.64)^{b}	17.73 (0.42)^{a}	.001
Age-at-onset (years)	17.9 (2.55)	15.77 (2.02)	17.21 (3.09)	15.44 (2.07)	-	-	
Duration of illness (years)	3.85 (2.31)	4.67 (2.65)	5.50 (2.65)	3.89 (1.96)	-	-	
Current hunger (score)	19.40 (16.71)	28.41 (18.79)	17.37 (14.02)	30.39 (24.02)	34.01 (26.06)	35.13 (18.46)	.10
Current thirst (score)	39.02 (27.90)	41.17 (24.41)	28.25 (14.02)	45.27 (16.16)	48.95 (25.44)	41.50 (20.88)	.23
Food familiarity (score)	88.90 (5.19)	90.86 (5.63)	91.64 (5.21)	92.11 (5.27)	95.00 (2.92)	92.80 (4.80)	.07
EDEQ (score)	3.41 (1.05)^{a}	2.20 (0.67)^{b}	4.02 (1.47)^{a}	2.24 (0.59)^{b}	1.92 (0.69)^{b}	1.46 (0.46)^{b}	.001
BDI-II (score)	9.00 (7.66)^{b}	5.07 (4.35)	7.50 (3.92)^{b}	5.22 (3.67	4.46 (3.74)	2.13 (1.46)^{a}	.01
FCQ-T (score)	33.85 (14.63)^{a}	38.27 (17.49)^{a}	63.00 (11.35)^{b}	43.19 (22.33)^{a}	34.00 (10.80)^{a}	33.53 (7.44)^{a}	.001
TSF$_{\text{Concept}}$ (score)	22.53 (19.56)	11.85 (12.13)^{a}	31.45 (28.02)^{b}	16.86 (24.53)	4.26 (2.79)^{a}	2.47 (1.85)^{a}	.001
TSF$_{\text{Clinical Impact}}$ (score)	16.44 (8.93)^{a}	8.46 (9.56)^{b}	19.78 (11.83)^{a}	7.00 (5.33)^{b}	5.90 (7.87)^{b}	4.92 (5.72)^{b}	.001

Note: *p* values were generated from ANOVAs. Values with different superscripts represent means that are statistically different among groups (columns) after post-hoc analysis ($p \leq .05$). Mean values (with standard deviations).

Abbreviations: BDI-II, Beck Depression Inventory-II; BMI, body mass index; EDEQ, Eating Disorder Examination Questionnaire; FCQ-T, Food Cravings Questionnaire-Trait; TSF, Thought-Shape Fusion Questionnaire.

2.2.2 | Tasting samples

In Study 2, milk was replaced by another milk-based product: chocolate ice cream, as a forbidden food for AN and BN because of its higher fat and calorie content (Wilson, 2000). Thus, four ordinary samples of chocolate ice cream containing low or high levels of fat and low or high levels of sweetness were presented at room temperature in 100 ml disposable Styrofoam cups, counterbalanced between subjects and reversed across sessions to control for taste fatigue, satiety and learning effects. The specific ingredients of the samples were milk, cream, water, sucrose, dextrose, glucose, chocolate powder, cocoa powder, and flavor. Sweetness (14.6% for low vs. 28.4% for high sweetness) and fat (1.2% for low vs. 11.4% for high fat content) were manipulated to increase differences across samples. Samples were stored at −18°C. Testing mixtures were prepared at the School of Agricultural, Forest and Food Sciences (Department of Food Science & Management, Bern University of Applied Sciences) according to previous studies on taste sensory and surface response method in AN and BN (Drewnowski et al., 1987; Sunday & Halmi, 1990).

2.2.3 | Two-alternative forced choice task and intake

As described in Study 1 but adding a swallow protocol to the sip-and-spit protocol (Eiber et al., 2002) to enhance biased cognitions about eating caloric foods in currently ill patients and to quantify the impact of these biases on discrimination judgments.

2.2.4 | Procedure

After providing an informed consent and the authorization to release/exchange confidential information, patients were contacted by phone to set three appointments at weekly intervals. The first week a structured diagnostic interview assessing axis I mental disorders (Mini-DIPS; Margraf, 1994) was carried out by telephone. During the second week eligible participants were required to fill out a set of online questionnaires (LimeSurvey), including the EDE-Q, short form of the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996), the Food Cravings Questionnaire-Trait (FCQ-T-reduced; Meule, Hermann, & Kübler, 2014) and the Thought-Shape Fusion Questionnaire (TSF-Trait, with TSF Concept and TSF Clinical Impact scores; Coelho et al., 2013). Finally, the experimental sessions were conducted in the third week in the clinics or in the psychophysiological laboratory at the universities of Fribourg/Luxembourg. In the case of control groups, the procedure was the same except for the diagnostic interview. During the experimental session, participants rated their level of thirst, hunger and food familiarity and performed the 2AFC task. Participants were asked to fast for 90 min prior to the experimental session. Participants completed flavor testing on the same day. Experimental sessions took about 90 min.

2.2.5 | Design and study outcomes

A quasi-experimental, cross-sectional design was used with six groups of participants: C-AN, R-AN, C-BN, R-BN, U-CT, and N-CT, and two counterbalanced testing protocols: sip-and-spit and swallow. For detailed information about materials and methods, see the protocol by Garcia-Burgos, Maglieri, Vögele, and Munsch (2018). As in Study 1, the primary outcomes were the parameters from the response data of the 2AFC task using the SDT approach: d' and response bias. The secondary outcomes were the percentage of correct responses and total intake (g) of each sample after the 2AFC task. Finally, the tertiary outcomes were the EDE-Q, BDI-II, FCQ-T-reduced and TSF-Trait scores.

2.2.6 | Sample size estimation and data analysis

Sample size calculations were performed using the G*Power software (version 3.13) and on the basis of our group's previous findings of small to medium effects on eating behavior in AN and BN (Munsch, 2014). Assuming two-sided tests with alpha = .05, beta = .2 and effect size $f = 0.20$, the required sample size was 80 to ensure power > 0.80 with sample distribution of $N_{\text{C-AN}} = 15$, $N_{\text{C-BN}} = 15$, $N_{\text{R-AN}} = 10$, $N_{\text{R-BN}} = 10$, $N_{\text{U-CT}} = 15$, and $N_{\text{N-CT}} = 15$. Notwithstanding, the final sample was reduced due to the limited number of patients meeting our strict inclusion/exclusion criteria.

To determine any initial differences among weight groups, a MANOVA with Group (C-AN vs. C-BN vs. R-AN vs. R-BN vs. U-CT vs. N-CT) as between factor on BMI, age at onset, duration of illness and the scores of EDE-Q, BDI-II, FCQ-T-Reduced, TSF-T-Reduced, hunger, thirst and food familiarity was used. Also, a mixed 6 Group × 2 (high vs. low sweetness) × 2 (high vs. low fat) × 2 (sip-and-spit vs. swallow protocol) ANOVA on ice cream intake was carried out. Any significant ANOVA was followed by Tukey's test for pairwise differences between groups. A chi-square test was applied to compare the percentage of correct responses among groups. The SDT metrics and inferential statistics were carried out as in Study 1, adding another protocol factor (sip-and-spit vs. swallow). Finally, Pearson's correlations were performed to test whether the sensory-discrimination ability of the groups was related to total intake during both the sip-and-spit and the swallow protocol.

2.3 | Study 3: Discrimination in populations with weight-related problems and eating disorders

2.3.1 | Data collection and data analyses

Three sets of d's were used from Studies 1 and 2. The first set was obtained from the groups with weight-related problems ($n = 54$): UW, OW (Study 1), and U-CT (Study 2). The second set was related to eating disorders ($n = 48$) and comprised four groups: C-AN, R-AN, C-BN, and R-BN (Study 2). As a control, the third set of normal weight

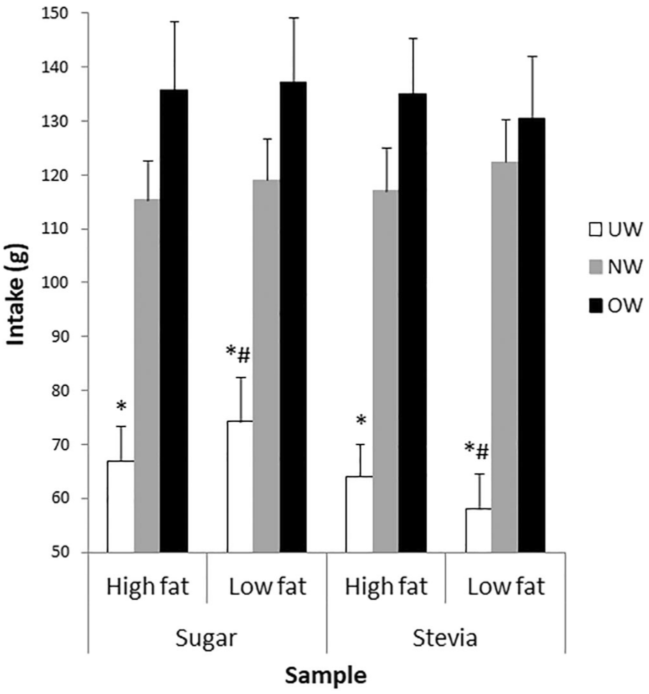


FIGURE 4 Intake of sweet-fat milk mixtures across the underweight (UW), normal weight (NW), and overweight (OW) groups during the two-alternative forced-choice task, including combinations between two sweeteners (caloric sugar and non-caloric stevia) with whole (high-fat) milk or reduced-fat (low-fat) milk

people was used ($n = 35$): NW (Study 1) and N-CT (Study 2). For each set, new estimates of population d' and variance parameters were calculated according to Bi's (2008) approach. As recommended by this approach, we used test statistic T for chi-square distribution to examine whether there was a significant difference among populations that share the same discriminative method but come from separate studies. When d's of Study 2 were used, only data from the sip-and-spit protocol were considered to maintain the same conditions as in Study 1. Finally, pairwise comparisons were performed with 0.95 confidence intervals.

3 | RESULTS

3.1 | Study 1: Discrimination in people with weight-related problems

Characteristics of participants. The mean values of age, BMI, hunger, thirst, food familiarity, and questionnaire scores, as well as statistical significance values are reported in Table 1. In terms of hunger and thirst, UW participants showed lower scores compared to the NW group. Regarding questionnaires, inverted U-shaped patterns on "Fun seeking" and "Reward" scores were observed across BMI, with a maximum in normal weight individuals. On the other hand, RC and TEFQ scores were significantly different among BMI groups, with higher cognitive restraint and uncontrolled eating in OW.

Saliva. No differences were detected among UW (3.27 ± 0.89, *M* ± SD), NW (3.37 ± 1.07), and OW (3.47 ± 1.35) participants ($F[2, 56] = 0.151$, $p = .86$, $\eta^2 = .005$).

Milk intake. The analysis revealed a significant main effect of BMI ($F[2, 55] = 3.16$, $p = .05$, $\eta^2 = .10$): UW (98.88 ± 80.55) consumed less than NW (156.32 ± 84.92) and OW (168.72 ± 110.89); differences were significant only between UW and OW ($p = .05$) (Figure 4). No other main effects or interactions were found to be significant (largest $F[2, 56] = 2.09$, $p = .15$).

Percentage of correct responses. No differences were detected among UW, NW and OW participants during judgment of sweetness (Figure 5, 1-2a) or fat content (Figure 6, 1-2a) ($\chi^2[6] = 7.94$, $p = .24$).

Signal detection theory indexes. The three groups showed discrimination abilities between sugar and stevia-related sweetness with d' values significantly greater than zero, under high-fat ($Z_{\mathrm{UW}} = 3.48$, $Z_{\mathrm{NW}} = 5.18$, and $Z_{\mathrm{OW}} = 10.54$; $ps < .001$; Figure 5, 1b) and low-fat conditions ($Z_{\mathrm{UW}} = 3.02$, $Z_{\mathrm{NW}} = 1.79$, and $Z_{\mathrm{OW}} = 8.50$; $ps < .05$; Figure 5, 2b). On the other hand, although a trend toward lower values of d' was noticed with higher BMI, no differences among BMI groups were observed for sweetness discrimination (largest $\chi^2[2] = 5.70$, $p = .06$).

Regarding fat discrimination, NW and OW exhibited moderate discrimination, with d' values larger than zero under sugar ($Z_{\mathrm{NW}} = 3.31$ and $Z_{\mathrm{OW}} = 5.11$, $ps < .001$; Figure 6, 1b) or stevia conditions ($Z_{\mathrm{NW}} = 3.68$ and $Z_{\mathrm{OW}} = 2.81$, $ps < .01$; Figure 6, 2b); while UW were unable to discriminate under either sweet condition (largest $Z = 1.39$, $p = .09$). On the other hand, significant differences among BMI groups were found when fat content levels were tested under sugar ($\chi^2[2] = 8.63$, $p < .01$) and stevia conditions ($\chi^2[2] = 6.31$, $p < .05$), with lower fat discriminability in UW compared to OW when sweetened with sugar (Figure 6, 1b; $p < .05$) and compared to NW when sweetened with stevia (Figure 6, 2b; $p < .05$).

Concerning the sweet-fat mixture effect (Table 3), a change from low- to high-fat content modified the perception of sugar-related ($\chi^2[2, 120] = 11.24$, $p < .001$) and stevia-related sweetness ($\chi^2[2] = 13.71$, $p < .001$) in all groups. In particular, increasing the fat content level enhanced the sweetness sensations of sucrose in UW compared to NW and OW ($ps < .05$), as well as the sweetness sensations of stevia in UW and NW compared to OW ($ps < .05$).

Finally, the analysis for response bias was significant ($\chi^2[11] = 691.34$, $p < .0001$). For biases in judgment of sweetness intensity, pairwise comparisons using 95% CIs revealed significant differences between UW (95% CI [0.73, 1.11]) and NW (95% CI [1.16, 1.34]) and between these and OW (95% CI [1.42, 1.81]) for high-fat milk tasting (Figure 5, 1-2c). In particular, when compared to NW, a liberal response bias (<1) in UW and a strict response bias (>1) in OW were found. Under low-fat milk conditions, significant differences among UW (95% CI [2.92, 3.13]), NW (95% CI [2.59, 2.75]), and OW (95% CI [0.94, 1.10]) were also observed, in the opposite direction: a strict response bias in UW and NW compared to the OW group. In contrast, no significant BMI-dependent differences were detected for biases in fat content judgment under sugar (95% CI [0.98, 1.14], [0.62, 1.24], and [1.01, 2.00] for UW, NW, and OW, respectively) or stevia

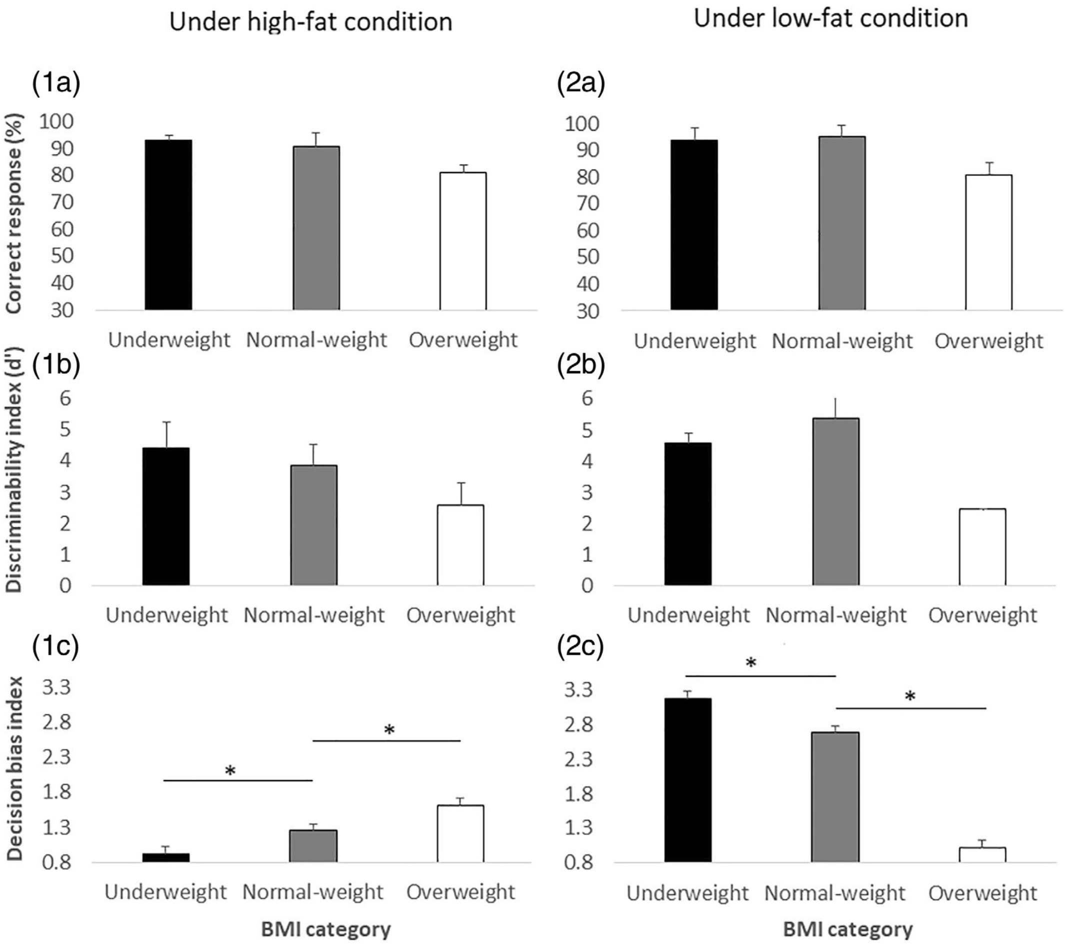


FIGURE 5 Discrimination of sweetness intensity. (a) Percentage of correct responses, (b) discriminability index, and (c) response/decision bias index of underweight (UW), normal weight (NW), and overweight (OW) groups under high-fat (left side) or low-fat (right side) milk conditions. * $p < .05$

(95% CI [0.99, 1.15], [0.88, 1.03], and [0.90, 1.06] for UW, NW, and OW, respectively) conditions (Figure 6, 1-2c).

Relationship between sensory-discrimination and total milk intake. Significant positive correlations were found between total intake and the groups' ability to discriminate between levels of fat under sugar and stevia conditions ($r = .29$ and $r = -30$, respectively; $ps < .05$), increasing from UW to OW, and the ability to discriminate between sweeteners under high-fat conditions ($r = .27$, $p < .05$).

3.2 | Study 2: Discrimination in patients with eating disorders

Characteristics of participants. The mean values of age, BMI, age at onset, duration of illness, hunger, thirst, food familiarity, and questionnaire scores, as well as the statistical significance values are shown in Table 2. In terms of BMI, body weight status increased from C-AN and U-CT to R-BN. Regarding EDEQ, BDI-II and TSF Clinical Impact scores, currently ill individuals (AN and BN) exhibited the highest values. Finally, BN also reported the highest score for food craving.

Ice cream intake. The analysis revealed significant Group × Protocol as well as Sweetness x Fat interactions (lowest $F[5, 69] = 2.91$, $p < .05$, $\eta^2 = .17$). No other main effects or interactions were significant (largest $F[1, 56] = 2.12$; $p = .15$, $\eta^2 = .03$). Upon visual inspection (Figure 7), while patients (currently ill and recovered AN and BN) exhibited a decrement in their intake from the sip-and-spit to the swallow protocol, control groups (N-CT and U-CT) showed the opposite pattern. Statistical analysis only confirmed significant differences between the sip-and-spit and the swallow protocol for R-AN, BN and U-CT ($ps < .05$). On the other hand, higher consumption of the sweeter samples was observed under the lowest concentration of fat ($p < .05$).

Percentage of correct responses. No effects were found under the sip-and-spit or the swallow protocol during judgment of sweetness (Figure 8, 1-2a) or fat content (Figure 9, 1-2a) (lowest $\chi^2[22] = 2.70$, $p = .10$).

Signal detection theory indexes. In terms of the ability to discriminate the sweeter ice cream (Figure 8, 1-2b) sample, all the groups showed high discrimination, with significantly greater d' values compared to zero, under both high-fat and low-fat levels as well as under

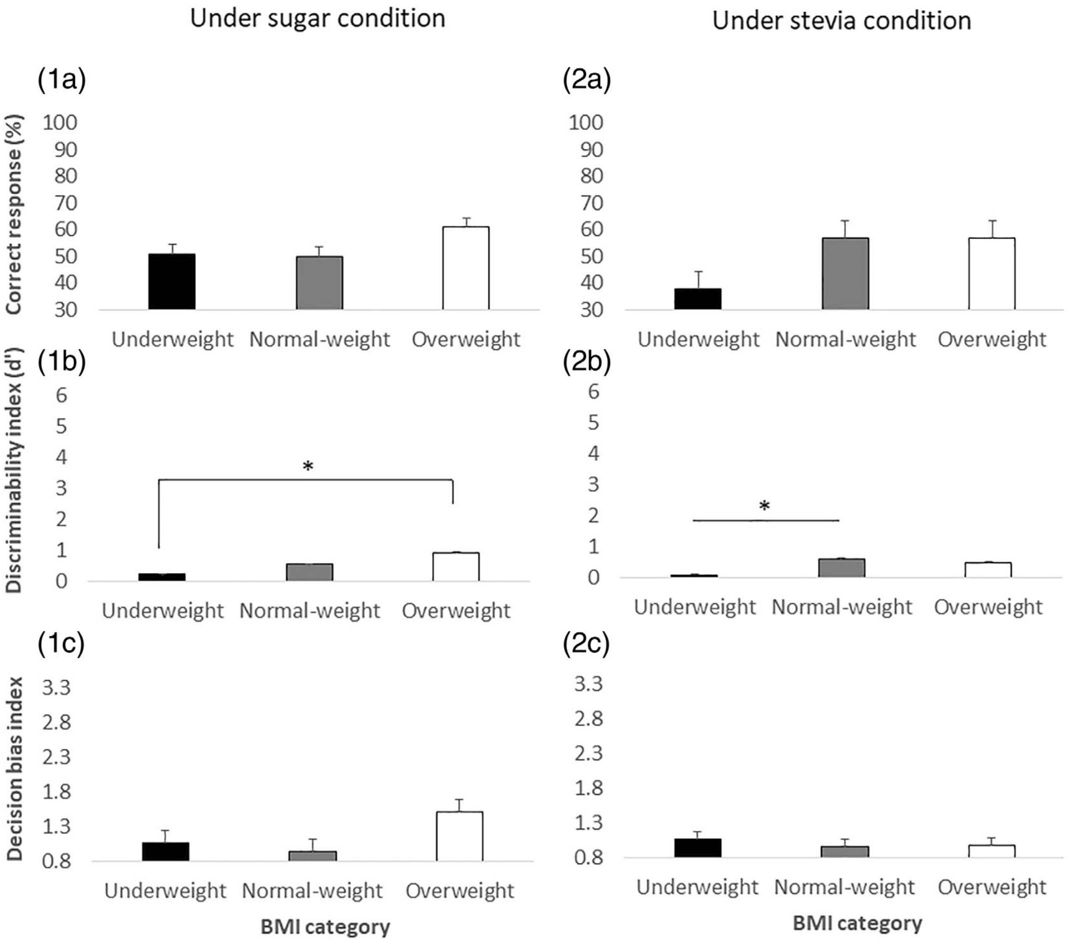


FIGURE 6 Discrimination of fat intensity. (a) Percentage of correct responses, (b) discriminability index, and (c) response/decision bias index of underweight (UW), normal weight (NW), and overweight (OW) groups under sugar (left side) and stevia (right side) conditions. * $p < .05$

TABLE 3 The sweetness–fat mixture effect. Discrimination of sugar or stevia-related sweetness intensity when the level of fat content is increased in underweight (UW), healthy normal weight (NW), and overweight (OW) groups. The concentration of sugar or stevia remains unchanged

Parameter	UW	NW	OW
Sugar: low-fat vs. high-fat milk conditions			
Percent correct (%)	60	48	52
Confidence self-report (0–50)	22	27	29
d' (discriminability index)	0.90^{a}	0.03^{b}	0.16^{b}
Decision/response bias index	0.71	1.09	0.96
Stevia: low-fat vs. high-fat milk conditions			
Percent correct (%)	58	64	46
Confidence self-report (0–50)	17	22	23
d' (discriminability index)	0.60	1.17	0.00
Decision/response bias index	0.97	0.74	1.06

Note: Values with different superscripts represent means that are statistically different among groups (columns) after post-hoc analysis ($p \leq .05$).

the sip-and-spit and the swallow protocols (lowest *Z*-value = 1.73; $p < .05$). On the other hand, when d's obtained from the different groups and protocols were compared, no significant differences were detected in any samples (largest $\chi^2[11] = 14.32$, $p = .21$).

Regarding the fattier ice cream judgment (Figure 9, 1-2b), all groups also showed discrimination with values significantly higher than $d' = 0$ for sweetness and fat level as well as for the sip-and-spit and the swallow conditions (lowest *Z*-value = 1.68; $p < .05$). On the other hand, although a tendency for better fat discrimination in the BN groups was observed in the sip-and-spit than the swallow protocol, statistical analysis did not confirm any significant differences among groups (largest $\chi^2[11] = 9.69$, $p = .55$).

Concerning the sweet-fat mixture effect (Table 4), changes in sweetness perception by switching from low-fat to high-fat content were found (lowest $\chi^2[11] = 28.94$, $p < .001$). Post-hoc comparisons revealed that an increase in fat content significantly increased judgment of sweetness by R-AN compared to C-AN under the sip-and-spit protocol ($p < .05$), as well as R-AN compared to C-BN, R-BN, and N-CT under the swallow protocol (*ps* < .05).

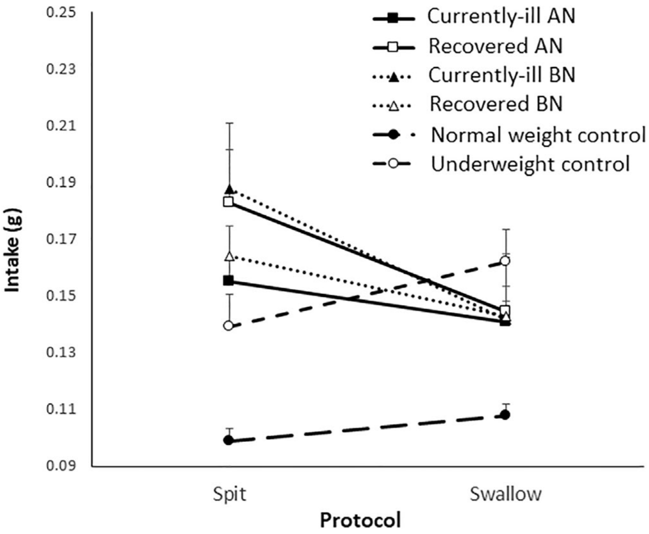


FIGURE 7 Intake of ice cream samples across the currently ill anorexia nervosa (C-AN), recovered anorexia nervosa (R-AN), currently ill bulimia nervosa (C-BN), recovered bulimia nervosa (R-BN), normal weight control (N-CT), and underweight control (U-CT) groups under the sip-and-spit and the swallow protocols

Finally, analysis for response bias was significant ($\chi^2[47] = 89.30$, $p < .001$). For biases in judgment of sweetness intensity, pairwise comparisons (Figure 8, 1-2c) under high-fat conditions revealed liberal response bias in C-AN compared to N-CT (95% CI [−1.44, −0.02]) during the sip-and-spit protocol; and in C-AN (95% CI [−2.20, −1.23]), C-BN (95% CI [−3.53, −0.53]), and R-BN (95% CI [−6.03, −0.44]) compared to the strict response bias in N-CT during the swallow protocol. On the other hand, the change in protocol affected R-BN, with an increase in response bias from the sip-and-spit to the swallow protocol (95% CI [0.34, 7.14]). Under low-fat conditions, an increase in response bias from the sip-and-spit to the swallow protocol was observed in C-AN (95% CI [0.11, 1.21]), while the opposite pattern was found in C-NT (95% CI [−1.08, −0.12]).

Regarding biases in judgment of fat intensity (Figures 9, 1-2C), pairwise comparisons under high-sweet conditions revealed a strict response bias in currently ill AN (95% CI [0.53, 1.82]) and BN (95% CI [0.45, 1.88]) patients compared to U-CT during the sip-and-spit protocol. Under low-sweet conditions, an increase in response bias from the sip-and-spit to the swallow protocol was observed in C-BN (95% CI [0.32, 1.98]).

Relationship between sensory-discrimination and total ice cream intake. Significant negative correlations were found between total intake and the ability to discriminate between levels of sweetness in low-fat conditions under the sip-and-spit ($r = -.26$, $p < .05$) and the swallow ($r = -.23$, $p < .05$) protocols.

3.3 | Study 3: Discrimination in populations with weight-related problems and eating disorders

Significant differences in sweetness and fat discrimination were detected among these three populations (the lowest $\chi^2[2] = 7.92$, $p < .05$) (Figure 10). In particular, participants with weight-related problems showed a reduced ability to discriminate between sweet items under high-fat conditions compared to the normal weight population ($p < .05$). On the other hand, patients with eating disorders exhibited a lower ability to distinguish between sweet samples when combined with low-fat conditions vis-à-vis those with weight-related problems, but a better ability to discriminate between fat ingredients compared to other populations (*ps* < .05).

4 | DISCUSSION

4.1 | Study 1: Discrimination in people with weight-related problems

Our findings did not support the hypothesis of an inverse relationship between the ability to distinguish sweet–fat stimuli and BMI (Hypothesis 1). On the one hand, there was a non-significant trend toward higher sensitivity in UW participants relative to OW. On the other hand, there were weight-dependent differences in the ability to detect changes in dietary fat concentrations in sugar-sweetened milk solutions but contrary to our prediction: higher BMI improved discrimination of fat-content levels. Indeed, individuals other than those with UW appeared to respond correctly to fat attributes. Interestingly, previous studies using 3-AFC procedures for threshold detection of simple fatty acid stimuli have reported higher thresholds in overweight compared to normal weight individuals (Stewart, Newman, & Keast, 2011; Stewart, Seimon, et al., 2011). It has been argued, however, that such studies neglect the role of other flavor cues (e.g., texture), which are important for detection and discrimination of fat content in naturalistic conditions or with real food (Tucker et al., 2017), as was the case with milk solutions in the present study.

Fat effects on sweetness should be mentioned in terms of the sweet-fat mixture effects as we found that UW participants perceived the fattier solutions as sweeter when they were forced to choose between two fat-milk solutions with the same sucrose or stevia concentration. It seems that changes in fat content (from 1.5% to 3%) were able to inflate sweetness judgments in this group. The influence of fat content on oral perception of sweetness intensity has been previously identified using nine-point category scales in normal weight women, who also judged very high-fat stimuli (e.g., 35% fat) as sweeter (Drewnowski & Schwartz, 1990). However, to the best of our knowledge, these mixture effects on perceived sweetness had not been previously observed in people with extreme BMI values such as obese and reduced-obese patients (Drewnowski et al., 1985) or underweight patients suffering from eating disorders (Drewnowski, 1993; Drewnowski et al., 1987).

Finally, as expected, response biases were a source of variance in relation to unhealthy BMI. OW individuals adopted a strict criterion for judging the sweeteners (i.e., they were conservative about reporting the sweeter sample) under the high-fat condition while the same

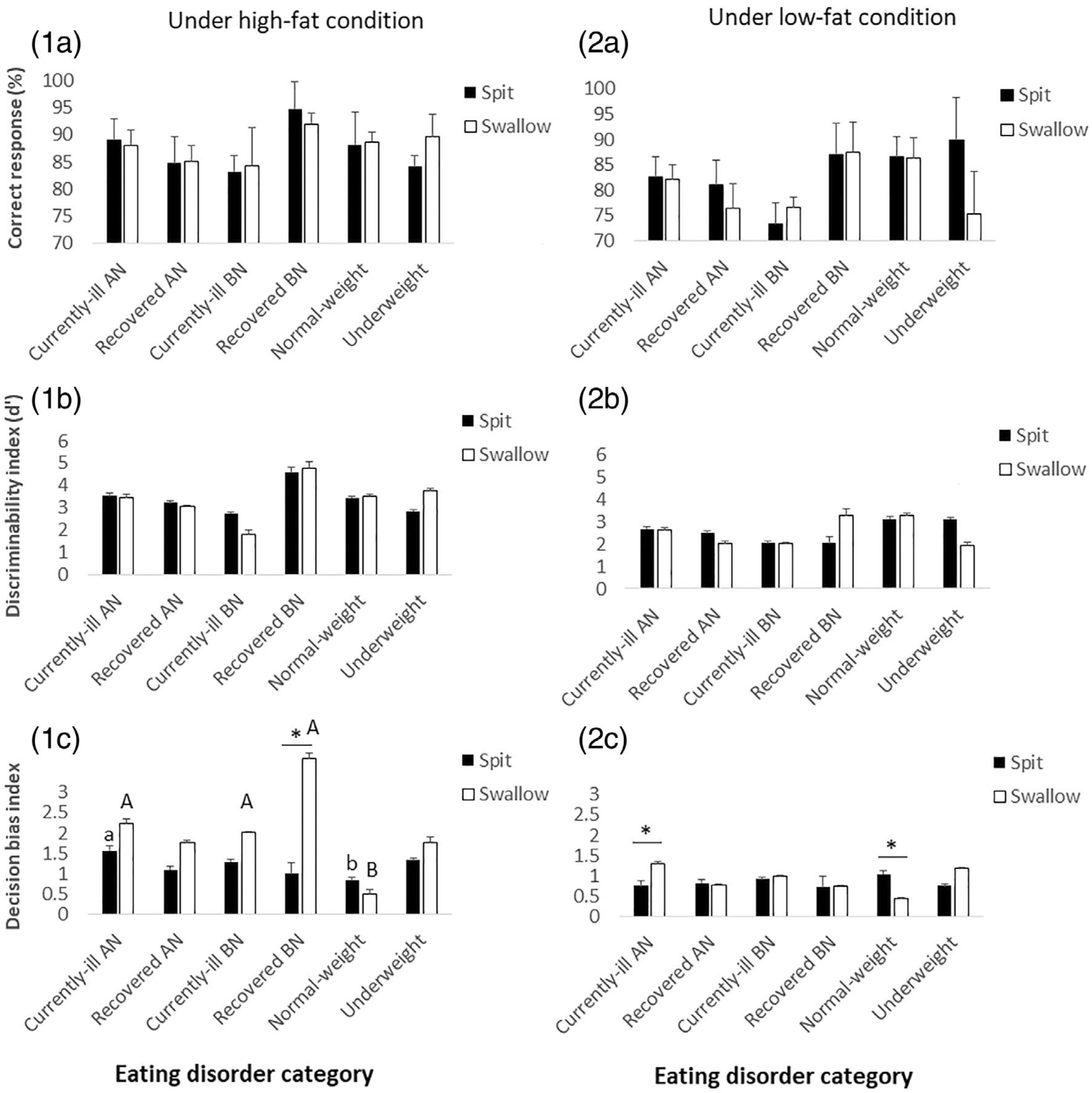


FIGURE 8 Discrimination of sweetness intensity. (a) Percentage of correct responses, (b) discriminability index, and (c) response/decision bias index of currently ill anorexia nervosa (C-AN), recovered anorexia nervosa (R-AN), currently ill bulimia nervosa (C-BN), recovered bulimia nervosa (R-BN), normal weight control (N-CT), and underweight control (U-CT) groups during the sip-and-spit or the swallow protocol and under high-fat (left side) or low-fat (right side) conditions. * $p < .05$ between spit and swallow conditions for the same group. Different lower-case letters indicate significant differences ($p < .05$) among groups in the spit condition, and different capital letters indicate a significant difference among groups in the swallow condition ($p < .05$)

strict tendency was observed under the low-fat condition in UW participants. This may reflect the greater experience that specific BMI groups have with each of these ingredients: more exposure to sweetened high-fat items in overweight individuals and more exposure to sweetened low-fat items in underweight ones. It is surprising that the only two existing studies using SDT methodology with obese samples have shown neither no difference nor lax response bias independently of whether participants were restrained or unrestrained eaters (Gardner, Brake, Reyes, & Maestas, 1983; Grinker, Hirsch, & Smith, 1972). Congruently with previous sensory literature in healthy subjects, these results highlight the potential role of biases in flavor perception measurement.

4.2 | Study 2: Discrimination in patients with eating disorders

Patients with eating disorders clearly (but not perfectly) discriminated between samples varying in sweetness (as indicated by the lowest *d′* of 1.82) and fat content (lowest $d' = 2.74$). As predicted, no differences in the groups' ability to discriminate between chocolate ice cream samples were observed (Hypothesis 2). This conclusion should be treated with caution as the possibility that fat or sweetness concentrations other than those used in our mixtures may still reveal differences among groups cannot be excluded. Nevertheless, our finding is consistent with the conclusions of Kinnaird et al.'s (2018) review

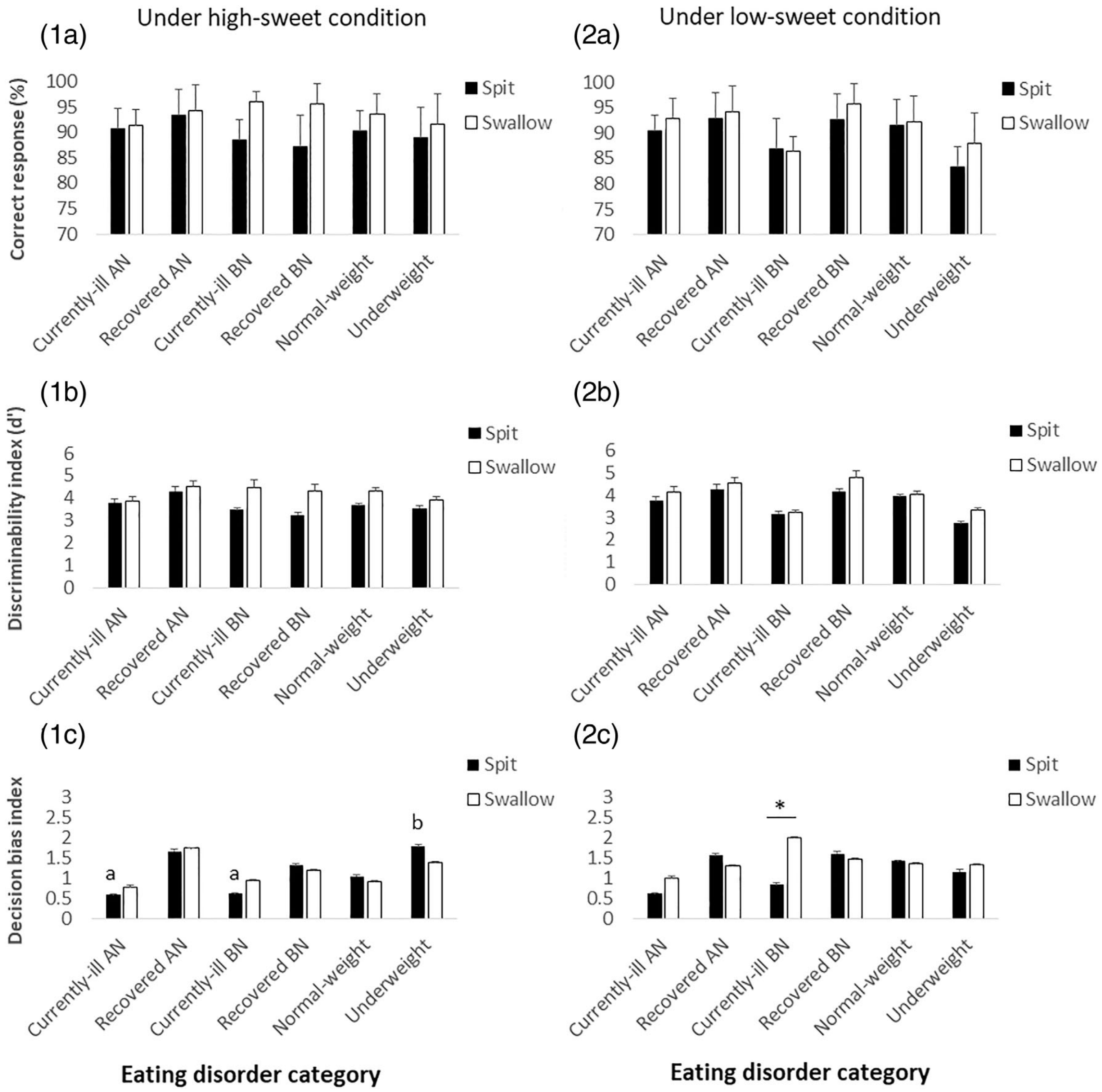


FIGURE 9 Discrimination of fat intensity. (a) Percentage of correct responses, (b) discriminability index, and (c) response/decision bias index of currently ill anorexia nervosa (C-AN), recovered anorexia nervosa (R-AN), currently ill bulimia nervosa (C-BN), recovered bulimia nervosa (R-BN), normal weight control (N-CT), and underweight control (U-CT) groups during the sip-and-spit or the swallow protocol and under high-sweetness (left side) or low-sweetness (right side) conditions. * $p < .05$ between spit and swallow conditions for the same group. Different lower-case letters indicate significant differences ($p < .05$) among groups in the spit condition

claiming that "the literature strongly suggests that perceived fat and sweetness intensity is not reduced or increased in AN when compared with healthy controls" (p. 780).

Regarding the response bias, both currently ill AN and BN patients exhibited a liberal criterion compared to normal weight controls, overjudging sweetness intensity of the samples. Consistently with Hypothesis 3, such biases were evidenced especially when patients swallowed the chocolate ice cream samples, which reveals the impact of the protocol on patients' judgments. This is in agreement with Eiber et al.'s (2002) findings that patients' response was also influenced by whether the samples were swallowed or not. It seems that in case of doubt, they had rather say "yes, this is the sweeter sample" than "no". Because high-calorie foods may elicit excessive fear of gaining weight, swallowing ice cream could have promoted their avoidance in responding to the sweeter samples. By contrast, the opposite occurred with fat content conditions in which both AN groups exhibited a lower (conservative) bias compared to underweight participants, underjudging fat intensity. Altogether, these data suggest that sweet rather than fat cues may be more accurate predictors of calories, and in turn body weight gain, in these patients. Consequently, patients may use a liberal bias to prevent failures in detecting high level of sweetness. This special role of sweet cues to prevent becoming fat in anorectic patients is also supported by the mixture effect finding, where the perception of sweetness is enhanced with increasing concentration of fat in R-AN.

TABLE 4 The sweetness–fat mixture effect. Discrimination of sweetness intensity when the level of fat content is increased in currently ill anorexia nervosa (C-AN), recovered anorexia nervosa (R-AN), currently ill bulimia nervosa (C-BN), recovered bulimia nervosa (R-BN), normal weight control (N-CT), and underweight control (U-CT) groups under the sip-and-spit or the swallow protocol. The concentration of sweeteners remains unchanged

	C-AN		R-AN		C-BN		R-BN		N-CT		U-CT	
Parameter	**Spit**	**Swallow**	**Spit**	**Swallow**	**Spit**	**Swallow**	**Spit**	**Swallow**	**Spit**	**Swallow**	**Spit**	**Swallow**
High sweetness: low-fat vs. high-fat conditions												
Percent correct (%)	65.38	57.69	54.55	69.33	47.08	56.26	34.17	53.61	49.21	50.65	53.01	50.00
Confidence self-report (0–50)	19.65	27.25	23.78	28.59	26.34	24.12	30.37	34.31	22.03	19.97	26.56	29.62
d′ (discriminability index)	1.12^{a}	0.55	0.32^{b}	$1.43^{\#}$	0.00	$0.44^{\dagger}$	0.00	$0.29^{\dagger}$	0.06	$0.05^{\dagger}$	0.21	0.00
Decision/response bias index	0.92	1.04	1.00	0.92	1.00	1.00	1.02	0.90	0.99	1.00	1.00	1.00
Low sweetness: low-fat vs. high-fat conditions												
Percent correct (%)	59.82	65.38	70.45	63.17	54.92	53.17	36.39	47.22	55.36	67.71	54.07	55.00
Confidence self-report (0–50)	21.94	24.14	20.06	26.69	26.62	27.84	27.62	28.97	20.87	20.22	22.78	29.22
d′ (discriminability index)	0.70^{a}	1.12	1.52^{b}	0.96	0.35	0.23	0.00	0.00	0.38	1.30	0.29	0.36
Decision/response bias index	0.97	1.09	0.93	0.92	1.00	0.98	1.18	1.00	1.00	0.97	0.97	0.97

Note: The level of sweetness was the same in both samples of the pair. Values with different superscripts (letters for the sip-and-spit protocol and symbols for the swallow protocol) represent means that are statistically different among groups (columns) after post-hoc analysis ($p \le .05$).

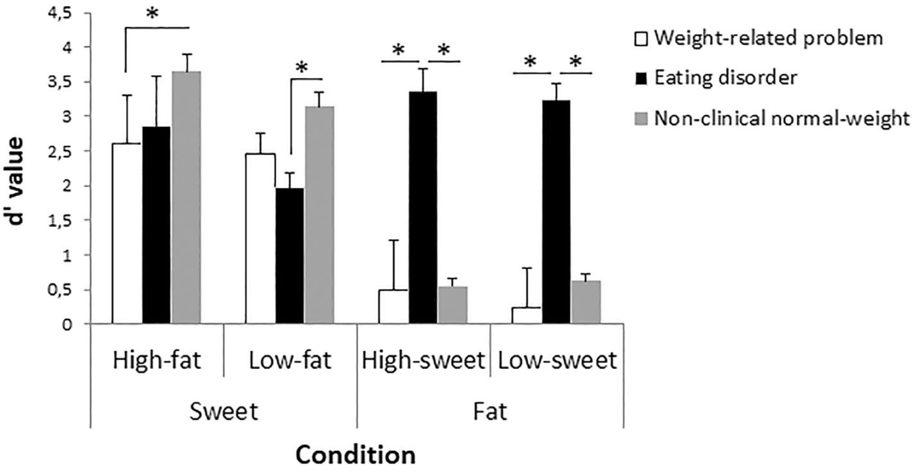


FIGURE 10 Discriminability index (*d*′ value) among populations with weight-related problems, eating disorders and healthy normal weight after judging the sweeter item under high-fat and low-fat conditions or judging the fattier item under high- and low-sweet conditions using a sip-and-spit protocol. * $p < .05$

4.3 | Study 3: Discrimination in populations with weight-related problems and eating disorders

Concerning the better flavor discrimination in patients with eating disorders compared to overweight people (Hypothesis 4), our results only supported the prediction for fat discrimination. Their heightened sensitivity in perception of fat intensity compared to healthy controls, as well as individuals with unhealthy weight, is in agreement with large sample size studies in this field such as Sunday and Halmi's (1990; $N = 132$). These authors reported that anorectic-bulimics and normal weight bulimics perceived solutions as fattier and showed elevated intensity ratings of lower fat solutions compared to controls. This is especially true in AN patients who self-report being hypersensitive to taste stimuli, particularly sweetness or fat, persisting even after weight restoration (cf. Kinnaird et al., 2018). Another interesting finding was the reduced ability to discriminate sweet samples in people with weight problems compared to healthy controls when testing with high-fat ingredients. Given the overrepresentation of undernutrition (64.8%), this result appears to be contrary to the inverse linear relationship between sensitivity to sweet taste and BMI, which predicts that individuals with heightened sensitivity to sweet taste tend to be leaner (cf. Stevenson, 2007).

4.4 | General discussion

As weight-related problems and eating disorders are intimately linked with abnormal ingestive behavior, it has been stated that these populations may also experience flavor perception dysfunction contributing to either the onset or maintenance of their unhealthy condition. In order to further investigate this issue, standardized SDT metrics combining Type I (false alarms) and Type II (misses) errors into a single analysis of discriminability and taking into account the participants' response biases have been introduced in this study. Our results confirm that traditional measures and data complemented with the SDT approach provide a more comprehensive view of sensory discrimination performance. For instance, while the percentage of correct responses measure did not identify the difficulties of underweight individuals to discriminate between fat levels in sugary products, the SDT data did. Judgment biases to respond to edible stimuli were also detected in both populations, a potential confounding factor to be controlled in future studies.

The relevance of this study is also considered in light of the scarcity of empirical evidence and the lack of detailed research on near-to-healthy normal weight populations, especially underweight samples. This is surprising as a large adult population is affected by underweight (about 8%), and even more by overweight (with a global age-standardized prevalence of about 35%), compared to severe (5%) and morbid obesity (about 2%) (NCD Risk Factor Collaboration, 2016; Stevens et al., 2012). These populations offer a critical window for prevention and treatment to reduce the prevalence of diet-related and nutrition-related diseases such as obesity and malnutrition. Likewise, this research is the first to compare sensory discrimination in individuals with weight-related problems and eating disorders. In this sense, the outstanding perception of fat intensity by patients with eating disorders, regardless of the diagnostic category or the stage of the disease, is of particular interest. Whether these differences are produced by the well documented fear of becoming fat and/or fat avoidance to these stimuli (cf. Chao et al., 2020) remains to be explored in these patients.

Unlike previous studies suggesting that patients with eating disorders most commonly exhibit gustatory dysfunction (for a review see Leland et al., 2021), we found response bias but not sensory differences among diagnostic categories or when compared to healthy subjects. In order to explain these contradictory results, it is possible that studies analyzing solely an isolated psychophysical gustatory function are likely not to accurately capture the complexity of flavor perception and of real food and beverages. Although taste and flavor have been often used interchangeably, the perception of flavor not only includes gustation but also trigeminal function and both orthonasal and retronasal olfaction.

Regarding the current debate on the contribution of taste sensitivity to eating behavior and the impact of sweet–fat perception on actual intake behavior, we found significant but not robust correlations between sensory discrimination ability and consumption. Moreover, our results show that regardless of composition, no specific BMI group/patient category consumed different amounts of flavor samples, that is, no group/category consumed more or less of the low-fat mixtures compared to the high-fat ones, or more or less of the high-sweet mixtures compared to the low-sweet ones. Therefore, our study is the first one using SDT that shows no influence of ingredient composition on eating behavior in any BMI group/patient category, which points to no clinical significance of sensory perception variability in actual intake behavior.

There are some limitations to be mentioned. Given that odors, as well as textural and visual cues, were not masked during sweet–fat content discrimination, other properties such as creaminess could have caused the greatest effect on the differences in fat content perception among BMI groups/patient categories. Another important factor is smoking. Although smoking more than 5 cigarettes per week was an initial exclusion criterion, this was replaced by low smoking level criterion (no more than 15 cigarettes per week) due to the difficulty in recruitment of eligible participants. Another issue related to flavor perception that differs with body weight or clinical status is the hedonic component (for reviews see Chao et al., 2020; Cox et al., 2016; Yu, 2017). Given the focus of this paper on sensory discrimination, the hedonic response to orosensory stimuli was not included in the present study. Nevertheless, this information is likely to help answer why differences exist within and between both unhealthy populations. Concerning the response bias, we did not ask the subjects to describe the strategy they applied in order to better understand the reasons behind. Nevertheless, given that these types of response bias were specific to sweetness discrimination, these results cannot be considered as part of a general tendency during testing, for example, of participants to systematically say “Yes” or “No” independently of the sample, as in the case of fatigue or boredom. Finally, the advantage of researching homogenous populations (especially in terms of age and body weight) limited the recruitment of males (our total sample only included 6.6% men) and therefore the generalization of these results to male samples.

5 | CONCLUSIONS

The heterogeneity and methodological limitations that characterize existing literature on the topic of flavor perception in unhealthy populations demand new and innovative methods. Indeed, there are good reasons to think that the ability to discriminate between sweet/fat ingredients and consuming sugary-fatty foods/beverages are not tightly linked. Therefore, the nature of the relationship requires precise and standardized measures. Testing sensory discrimination in populations with weight-related problems and eating disorders through the standardized metrics offered by SDT separately from the response bias may offer distinct advantages. We hope the present results along with future research applying other flavor discriminative and non-forced choice methods and SDT will contribute to disentangle the instances when altered flavor sensitivity may represent a component in the wider altered eating and drinking behavior observed in these populations.

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DATA AVAILABILITY STATEMENT

The data are available upon request to the corresponding author indicating the intended objectives and specific details of the use of data and will only be provided consistent with existing ethical approvals and governance standards in place for the data.

ORCID

David Garcia-Burgos https://orcid.org/0000-0002-3730-9111

ENDNOTE

[1] Although "fat perception" is a debatable term as it is related to flavor and/or texture perception, we use this term in order to distinguish it from the term "sweet perception/discrimination".

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