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Exploring the hedonic and incentive properties in preferences for bitter foods via self-reports, facial expressions and instrumental behaviours

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ABSTRACT

Preferences for and consumption of bitter foods such as vegetables and fruit are important in addressing the epidemic of obesity as healthy dietary patterns contribute to its prevention. However, few studies have been undertaken to understand the preference for bitter-tasting foods. A generally accepted but not proven explanation is that these acquired preferences involve changes in affective and motivational processes in order to overcome the innate rejection of bitter tastes. To examine this issue we compared the hedonic and incentive responses to bitter substances among bitter likers and dislikers. In addition, the effects of hunger, stress and weight concern on bitter preferences were also explored. Fifty-nine healthy adults (age = 24.8 ± 6.3; body mass index = 22.0 ± 2.8) were divided into bitter likers and bitter dislikers according to their food preferences. Both groups sampled the unreinforced flavours of coffee, beer, chocolate and grapefruit under four motivational states induced by static pictures (neutral, food, stressor and obesity) at the time of testing. The results showed that the bitter solutions elicited less aversive responses (higher hedonic ratings and less intense disgust reactions) and fewer avoidance behaviours (slower response time and lower amount of water for rinsing) in bitter likers after viewing neutral images. On the other hand, likers exhibited a further reduction in disgust to coffee after viewing stressor pictures, and also drank more water after tasting chocolate following the obesity pictures, compared with the dislikers. The expression of disgust increased in bitter likers, as well as the amount of water used to rinse the mouth, after tasting chocolate following pictures showing obesity compared with pictures showing food. These results show, for the first time, not only the implication of affective and incentive components in reversal of the predisposition to reject bitterness but also the motivational modulation of the expression of rejection of bitter tastes in humans.

Introduction

The adoption of healthy dietary patterns represents an important strategy for preventing and combating the worldwide obesity epidemic. In particular, the consumption of fruit and vegetables has been reported to reduce the risk of obesity (He et al., 2004). However, some of these foods such as citrus fruits, cruciferous vegetables and green leafy vegetables are bitter (Drewnowski & Gomez-Carneros, 2000) and generally disliked due to the instinctive rejection of the bitter taste (Steiner, 1979). Conversely, other bitter foods such as alcohol or coffee, also related to obesity and major diseases (Lahti-Koski, Pietinen, Heliövaara, & Vartiainen, 2002), are consumed and enjoyed by large segments of the population. Unfortunately, the mechanisms that underlie reversal of the predisposition to reject bitter tastes and the related shift in preference for bitter foods remain to be established (Stein, Nagai, Nakagawa, & Beauchamp, 2003).

In sensorial terms, one explanation is that the addition of sweeteners can make up for the unpleasant bitterness of beverages and food (Mattes, 1994). In fact, sweet-tasting compounds, odorants and textures have been employed by the pharmaceutical and food industries to mask bitterness and improve the taste properties, and thus the acceptance, of these foods (Gaudette & Pickering, 2013). An alternative explanation is that individuals learn to like bitter substances by experience. For instance, different types of learning seem to lead preferences for bitter foods, including nonassociative forms such as mere exposure (Stein et al., 2003) in which exposure to a novel flavour without any explicit

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consequence increases liking for that flavour. According to its long history as a mechanism for development of extreme emotional responses, another robust candidate is associative learning (Rogers, Richardson, & Elliman, 1995; Rozin & Vollmecke, 1986; Yeomans, 2006), suggested to be strong enough to operate against our innate rejection of unpalatable foods (Drewnowski, 1997; Rozin & Vollmecke, 1986). In its standard form, associative learning of preferences involves pairing a flavour (defined as the combination of taste, odour and chemical sensations) with attractive attributes such as the sensory–affective features (e.g. the pleasantness of the sweet taste) and/or post-ingestive components (e.g. calories or psychoactive effects) of food; with the former mediating the acquisition of hedonic value (i.e. orosensory pleasure) and the latter mediating the acquisition of incentive value (i.e. disposition to eat according to the anticipated consequences of ingestion) (Berridge & Robinson, 1998; Dickinson & Balleine, 2002). It is thanks to these associations that flavour cues seem to direct diet choice and intake by reminding us about the positive properties of the food. Participants exposed to these pairings appear to increase their liking and/or willingness to consume the bitter taste (Capaldi & Privitera, 2008; Richardson, Rogers, & Elliman, 1996; Yeomans, Mobini, & Chambers, 2007; Yeomans, Spetch, & Rogers, 1998).

However, the hedonic and incentive qualities of bitter foods in people who like them have not yet been explored empirically in humans, and this was the first objective of the present research. To do this, explicit (subjective ratings) and implicit measures (facial expressions and instrumental behaviours) that are particularly sensitive to both hedonic and incentive processes (Berridge & Robinson, 2003) were examined in a bitter solutions-tasting task. Subjects were asked to sample four bitter tastes: sugar-free chocolate liquor, alcohol-free beer, decaffeinated coffee and sweetener-free grapefruit juice. The bitter tastes used here were delivered in the absence of sweetener or post-ingestive outcomes so that observed responses depended on the (learnt) properties of the bitter tastes rather than on the immediate impact of the biologically relevant consequences such as alcohol or caffeine or the bitter masking effects of sugar and sweeteners. Based on the associative hypothesis, people who like bitter-tasting foods would be expected to show an acquired increase in hedonic responses and/or the desire to consume unreinforced bitter tastes compared with bitter dislikers. In order to control for alternative explanations for such differences between bitter likers and dislikers, especially in terms of genetic differences in sensitivity to some bitter compounds and the history of interaction with bitter foods, the threshold for detection of bitterness and bitter taste familiarity were evaluated as well.

The fact that foods are composed of different reinforcing attributes and that each of these attributes can participate in the association process is well established. Nevertheless, it is not clear which class of desirable properties may be acquired by bitter tastes. On the basis of the most psychometrically validated motives related to food choice and eating (Jáuregui-Lobera & Bolaños Ríos, 2011; Renner, Sproesser, Strohbach, & Schupp, 2012; Rozin & Vollmecke, 1986), distinct incentive values can be considered, including the regulation of affective states in the case of the psychoactive components, the satiation power in the case of calories, or even weight control in the case of beliefs about the potential weight control/health benefits of bitter vegetables and fruits. However, the role of these incentives in the preference for bitter tastes has not been examined. A useful strategy to clarify this issue is manipulation of the motivational state at the time of testing. The theoretical basis for this strategy is the incentive-learning theory (Dickinson & Balleine, 2002). This theory holds that the incentive properties acquired by food cues (e.g. anticipation of the tension-reducing effects) through their association with reinforcing attributes (e.g. alcohol) exert a general motivational influence on appetitive behaviours (e.g. enhancing the flavour preference for alcohol), which are modulated by *relevant* motivational states (e.g. tension but not thirst or hunger in the case of the alcohol reinforcer). An implicit assumption of this theory is that if a flavour is paired with, for example, the tension-reducing properties of alcohol, then the experience of increased tension should increase the desire to consume the flavour. Current evidence is provided by studies where the desire to drink alcoholic beverages seems to increase only among alcohol consumers who are exposed to both alcohol cues and a negative mood (Cooney, Litt, Morse, Bauer, & Gaupp, 1997; Fouquereau, Fernandez, Mullet, & Sorum, 2003; Higgins & Marlatt, 1975). Similarly, studies on the impact of deprivation states have reported, for example, that flavour preferences conditioned by caffeine are modulated by caffeine need (Smit & Blackburn, 2005; Tinley, Durlach, & Yeomans, 2004; Yeoman, Jackson, Lee, Nesic, & Durlach, 2000), or that more coffee drinking occurs with higher levels of stress (Conway, Vickers, Ward, & Rahe, 1981). Furthermore, the fact that modulation of acquired preferences by relevant motivational states is to some extent reinforcer-specific is supported by studies with hunger (Kern, McPhee, Fisher, Johnson, & Birch, 1993; Mobini, Chambers, & Yeomans, 2007; Yeomans & Mobini, 2006) in which a greater increase in the liking for a flavour paired with sucrose (calorie containing) but not with aspartame (calorie free) has been observed in participants trained and tested in a hungry vs. sated state (Mobini et al., 2007).

Therefore, taking into account that motivational states modulate the hedonic/incentive properties of flavours associated to relevant reinforcers (Dickinson & Balleine, 2002), the second objective of this study was to determine whether hunger-reducing, tension-reducing and weight control-enhancing properties of calories, psychoactive actions and weight control/health benefits are involved in the preference for bitter tastes. This objective was measured by assessing the effects of the presence vs. absence of relevant motivational states during the bitter solutions-tasting task. We hypothesised that if hunger-reducing is the incentive property presumed to underlie the preference for bitter tastes in people who like bitter-tasting foods, then the induction of hunger should increase the pleasure/desire for the calorie-associated flavours (e.g. chocolate). In a similar way, the induction of stress should increase the pleasure/desire for the pharmacological-action-associated flavours (e.g. beer/coffee), and the induction of weight/health concern for the health-associated flavours (Sun, 2008; e.g. grapefruit). Finally, given the validity of static pictures to induce hunger (Schüssler et al., 2012) and positive/negative moods (Mason, Light, Escher, & Drobes, 2008), the target motivational states were induced by images just before participants tasted the solutions.

Methods

Subjects

Fifty-nine healthy subjects of the Pontificia Universidad Católica Argentina (Argentina) were selected from a group of 144 subjects using an index of preference for bitter foods (IPBF) which was calculated by adding the scores of a food preference questionnaire (FPQ, with Cronbach's alpha (α) of .88), a food frequency questionnaire (FFQ, α = .51) and a version of the National Cancer Institute Diet History Questionnaire (DHQ, α = .83). These instruments asked questions about a variety of bitter-tasting foods, including the foods used in the study. Subjects with extreme scores on the IPBF were assigned to two groups: bitter dislikers (scores <40th percentile) and bitter likers (scores >60th percentile). Subjects also answered a Food Choice Questionnaire (FCQ, α = .88; Jáuregui-Lobera & Bolaños Ríos, 2011) that measured factors that influence people's dietary choices. Exclusion criteria were aversions, smoking, illnesses, history of eating disorders, dieting, diabetes, and allergy to the foods offered. Subjects' characteristics are summarised in Table 1. The experiment was approved by the Ethics Committee of the Pontificia Universidad Católica Argentina.

Procedures

Participants first tasted the 6-*n*-propylthiouracil (PROP) solutions presented in 10-ml plastic cups to assess bitter-taste sensitivity. The experiment then consisted of four blocks (two blocks/session/day) and was conducted in an individual booth (at 22 ± 2 °C) equipped with a computer (Samsung NP300E4AH) for presentation of instructions and motivational pictures and to record subjects' responses. Each block lasted about 25 min and included the following: (1) a record of food eaten previously to control the level of caloric intake; (2) presentation of one category of pictures; (3) self-reports of hunger, stress and weight concern levels before and after presentation of the pictures for motivational evaluation; (4) the bitter solutions-tasting task in which the subjects were asked to sample food solutions in blind tasting (i.e. without knowing what the food was) and extinction conditions (i.e. the solutions were delivered in the absence of sweetener or post-ingestive outcomes); and (5) rating of hedonic, incentive, familiarity and bitter intensity of each food solution.

Regarding the bitter solutions-tasting task, after rinsing with water (presented in 120-ml thermal cups) before each solution, participants were instructed to swirl the relevant PROP/food solution around in their mouth and to expectorate (sip-and-spit technique). There was a period of 120 s between presentation of the different solutions. A 400-ml transparent plastic cup with 250-ml of fresh mineral water was available at all times during tasting, though the real purpose of this additional water was to measure mouth rinsing as an instrumental behaviour.

PROP taste sensitivity and bitter intensity of the food solutions

Three concentrations of PROP (Sigma Chemical Company, St Louis, USA) were used: 1.0×10^{-5}, 3.2×10^{-5} and 6.0×10^{-4} mol/l (regular PROP series for taste detection thresholds; Drewnowski, Henderson, & Shore, 1997). They were presented from lower to higher intensity to prevent saturation of the receptors. The bitter sensations were characterised using a Time-Intensity software (Galmarini, Zamora, & Chirife, 2009) which provided the maximum intensity reached (I_{max}; 0–100; 0 = not at all bitter and 100 = extremely bitter). The question asked was: "How bitter do you find the solution now in your mouth?" PROP taster status of the participants was determined on the basis of their I_{max}. Those who gave a $PROP_{I_{max}} > 30$ at 1.0×10^{-5} and at 3.2×10^{-5} were classified as supertasters, a $PROP_{I_{max}} > 30$ at 3.2×10^{-5} and at 6.0×10^{-4} as tasters, and a $PROP_{I_{max}} < 30$ at 3.2×10^{-5} and at 6.0×10^{-4} as non-tasters. Subjects also rated the bitter intensity of the food solutions, obtaining $S_{I_{max}}$. The rating method, question and software were the same as for the PROP solutions.

Table 1
Subjects' characteristics.

Characteristic	Bitter dislikers	Bitter likers
Male (*n*)	12	9
Female (*n*)	16	22
Age (years)	23.8 ± 4.5	25.8 ± 8.1
BMI (kg/m^2)	22.1 ± 2.7	21.9 ± 2.9
IPBF score	114.0 ± 30.7	191.6 ± 22.4***
FPQ score	80.9 ± 18.2	128.2 ± 12.6***
FFQ score	2.8 ± 2.2	4.8 ± 2.8***
DHQ score	33.3 ± 12.0	58.8 ± 18.5***
FCQ score: health	15.8 ± 6.8	16.4 ± 3.7
FCQ score: mood	11.4 ± 3.3	13.6 ± 4.1*
FCQ score: convenience	12.6 ± 4.5	12.1 ± 3.5
FCQ score: sensory appeal	13.9 ± 1.6	12.9 ± 2.6
FCQ score: natural content	6.2 ± 2.4	6.3 ± 2.2
FCQ score: price	7.1 ± 2.5	7.0 ± 1.8
FCQ score: weight control	6.2 ± 2.5	6.7 ± 2.1
FCQ score: familiarity	6.0 ± 1.9	5.9 ± 2.1
Kcal before neutral pictures	459.4 ± 275.3	446.2 ± 175.1
Kcal before food pictures	456.5 ± 287.4	431.1 ± 180.4
Kcal before stressor pictures	471.9 ± 263.4	438.2 ± 202.4
Kcal before obesity pictures	466.6 ± 276.2	439.8 ± 213.7

Note: BMI: Body mass index; IPBF: Index of preference for bitter foods; FPQ: food preference questionnaire; FFQ: food frequency questionnaire; DHQ: Diet History Questionnaire (Spanish translation); FCQ: Food Choice Questionnaire. Kcal: kilocalories. $^{*}p \leqslant .05$, $^{***}p < .001$, significant differences for comparisons between bitter conditions. Data expressed as mean ± standard deviation.

Food solutions

Subjects were offered 5 ml of non-caffeine coffee (Nescafé Decaf, Nestlé, Argentina; prepared in water at a concentration of 3.75% w/v), sugar-free chocolate liquor (natural cocoa liquor, refined; Cargill Agricola S.A., Brazil), alcohol-free beer (Quilmes Lieber, Cervecería y Maltería Quilmes S.A.I.C.A.y G, Argentina), and hand-squeezed pink grapefruit juice in 10-ml plastic cups at 55 °C (coffee/chocolate) or 25 °C (beer/grapefruit juice). No sugar/sweeteners were added to the solutions. Physical and chemical parameters of the stimuli are shown in Table 2.

Induction of motivational states

Four categories of pictures (33 colour photographs/category) were used to induce control, hunger, stress or weight/health concern states: neutral, food, stressor and obesity, respectively. Each set of images was presented for a total time of 10 min, and each picture was presented on average twice for 10 s. Although the pictures had been successfully used in a preliminary study, their motivational effects were evaluated again on a nine-point scale, with 1 = not at all and 9 = extremely, before and after exposure in three dimensions: hunger ("Are you hungry right now?"), stress/tension ("Are you stressed/tense right now?") and weight/health concern ("Are you worried about your weight/health right now?"). The neutral images consisted of objects (e.g. door, table) taken from the GAPED database (Dan-Glauser & Scherer, 2011), the food images showed savoury/sweet meals (e.g. steak, pizza), stressor images showed everyday physical stress events (e.g. heavy traffic, pollution), and obesity pictures consisted of people with weight concerns (e.g. on bathroom scales, attempting to button up their trousers).

Hedonic, incentive and familiarity ratings

Explicit hedonic value was rated on a nine-point hedonic scale (with 1 = dislike extremely, a neutral point at 5 = neither like nor dislike, and 9 = like extremely) by answering the question: "How pleasant is the food now in your mouth?" To account for the incentive value and familiarity (i.e. knowledge of and experience with the flavour), subjects rated each food stimulus using nine-point category scales (with 1 = not at all and 9 = extremely). The questions were: "How much do you want to eat this food?" and "How familiar are you with this food?", respectively.

Facial affective responses

Implicit hedonic value was provided by analysis of two facial expressions, disgust and happiness, using the FaceReader 4 software (Noldus Information Technology, The Netherlands) that scaled each facial expression from 0 (not present at all) to 1

Table 2
Characteristics of food solutions.

Solution	Viscosity	pH	Fat (%)	Protein (%)	Carbohydrate (%)	Theobromine (%)	Caffeine (%)	$S_{I_{max}}$ [b]	Familiarity ratings[b]
Coffee	<10	4.9	0.2	6.5	3.3	0.0	0.0	68.9	7.3
Beer	<10	4.6	0.1[a]	0.2[a]	8.1[a]	0.0	0.0[a]	34.4	6.4
Chocolate	>1000	6.0	52.0	14.4	0.0	1.2	0.2	68.3	7.6
Grapefruit	<10	3.0	0.0	0.5	8.9	0.0	0.0	40.3	8.4

Note: Nutrient data describe company determinations, expressed on a weight basis in the form of a percentage (%). Viscosity was measured with a rotational viscometer (Brookfield DV-LVT; Brookfield Engineering Laboratories, Middleboro, USA), and pH with a pH-metre (HANNA-pH 210, Germany), except for chocolate (determined by IOCCC method, 9/1972, in 10% solution). $S_{I_{max}}$: maximum intensity reached (I_{max}; 0–100; 0 = not at all bitter and 100 = extremely bitter). Familiarity rated using 9-point category scale (1 = not at all and 9 = extremely).

[a] Nutrient estimation data of non-alcoholic beer (USDA's National Nutrient Database for Standard Reference, 2014).

[b] Under the control state (i.e. after viewing the neutral pictures).

(maximum intensity of the fitted model) (see Garcia-Burgos & Zamora, 2013). The software was able to analyse approximately 80% of the video frames. To standardise the measurements and compare facial expressions (of different duration and latency), the timeframe for analysis was the ten seconds before and after tasting the food solutions. Facial analysis before tasting served as baseline. The intensity of each facial expression was calculated by subtracting the average intensity of the baseline period from the average intensity after tasting.

Additional rinsing response time and water used for rinsing

Two implicit measures of a solution's incentive value were selected: the amount of water (AW, grams) used to remove the negative sensations and the rinsing response time (RT, seconds), calculated as the difference between the time of onset of tasting and rinsing (lips in contact with the cup in both cases). The rationale was that if the incentive properties are typically measured by the increase in instrumental behaviours to obtain food reinforcement, then the attribution of new incentive value to the unpleasant bitter taste should conversely produce a reduction in the magnitude of escape responses to bitter sensations signalling food reinforcement, such as rinsing the mouth with water.

Study design and statistical analysis

The study had a mixed factorial design with Bitter condition (disliker vs. liker) as the between-subjects factor, and Picture category (neutral vs. food vs. stressor vs. obesity) and Solution (coffee vs. beer vs. chocolate vs. grapefruit) as the within-subjects factors. To control for possible sequence/fatigue/practice effects of the presentation of the picture categories and solutions, an intragroup counterbalance was used in accordance with D'Amato's (1970) algorithm. The normality of the distribution of all variables before performing the analysis was assessed. Hedonic/incentive/familiarity ratings, as well as RT, were skewed and therefore log-transformed for analysis. Continuous variables were presented as mean or geometric mean. Comparisons between bitter conditions for age, body mass index (BMI), questionnaires (FPQ, FFQ, DHQ, and FCQ-SP), IPBF and caloric intake (calculated using the USDA database, release 25) were tested using independent-samples *t*-tests. To assess whether induction of motivational states by viewing the pictures was successful, a 2 (Bitter condition) × 2 (Time: before vs. after) × 3 (Motivational dimension: hunger vs. stress vs. weight/health concern) × 4 (Picture category: neutral vs. food vs. stressor vs. obesity) ANOVA was performed on subjective ratings. To detect differences in taste sensitivity, a 2 (Bitter condition) × 3 (PROP concentration: 1.0×10^{-5}, 3.2×10^{-5}, 6.0×10^{-4}) ANOVA on $PROP_{I_{max}}$ was used. The distribution of the PROP taster status (non-tasters, tasters and supertasters) by bitter condition was evaluated by χ^2 tests.

To assess the first hypothesis regarding whether bitter likers show learnt increases in pleasure and desire for the bitter taste compared to dislikers, 2 (Bitter condition) × 4 (Solution) ANOVAs were performed on the $S_{I_{max}}$, hedonic/incentive/familiarity ratings, intensity of facial expressions (disgust/happiness), AW and RT during the control motivational condition (i.e. after viewing the neutral images). To assess the second hypothesis regarding whether hunger-reducing, tension-reducing and weight control-enhancing properties underlie preferences for bitter tastes in bitter likers, 2 (Bitter condition) × 3 (Picture category: food vs. stressor vs. obesity) × 4 (Solution) ANCOVAs were performed on the $S_{I_{max}}$, hedonic/incentive ratings, intensity of facial expressions (disgust/happiness), AW and RT (using the values of each dependent variable for each solution during the control motivational state as covariates). Post-hoc comparisons used Tukey's tests. Where appropriate, the levels of significance were adjusted for multiple comparisons by Bonferroni's correction. $p \leqslant .05$ was considered significant.

Results

Subjects and effectiveness of motivational manipulation using pictures

The mean values of age, BMI, IPBF, questionnaire scores and caloric intake are shown in Table 1. Age, BMI and total caloric intake did not differ between bitter likers and dislikers (highest $t[57] = -1.07$, $p = .29$). FPQ ($t[57] = -11.75$), FFQ ($t[57] = -2.97$), DHQ ($t[57] = -7.30$) and IPBF ($t[57] = -11.26$) scores were higher in likers than dislikers ($ps < .001$). Regarding FCQ-SP, likers rated the effects of food on mood ($t[57] = -2.16$, $p < .05$) as a more important factor in their food choices than did dislikers.

Regarding the motivational effects of images (Table 3), a significant Time × Motivational dimension × Picture category interaction was found ($F[6, 342] = 23.64$, $p < .001$, $\eta^2 = .293$). No Bitter condition effect or interaction with Bitter condition were observed (all $Fs < 1$). As expected, post hoc analysis showed that viewing the food pictures increased hunger ratings ($p < .001$). The pictures with stressors increased stress/tension ratings ($p < .001$), while the obesity pictures decreased hunger ratings ($p < .01$) and increased health concern ratings ($p < .001$). No other significant changes between before and after viewing the pictures were determined ($ps \geqslant .09$).

Taste sensitivity

PROP intensity ratings showed a significant main effect of Concentration ($F[2, 114] = 127.93$, $p < .001$, $\eta^2 = .69$). No Bitter condition effect or interaction Bitter condition × Concentration were observed (all $Fs < 1$). Analysis of the means showed that the 1.0×10^{-5} was rated as less bitter than the 3.2×10^{-5}, and the 3.2×10^{-5} as less bitter than the 6.0×10^{-4} mol/l concentration

Table 3
Motivational effect of pictures.

Category of photographs	Motivational dimension	Before	After
Neutral	Hunger	4.5 ± 2.9	4.3 ± 3.0
	Stress	4.1 ± 2.4	4.1 ± 2.8
	Weight/health concern	6.8 ± 2.1	6.6 ± 2.4
Food	Hunger	4.2 ± 2.9	5.7 ± 2.9***
	Stress	4.0 ± 2.6	3.9 ± 2.4
	Weight/health concern	6.8 ± 2.8	6.6 ± 2.2
Stressor	Hunger	4.5 ± 3.1	4.6 ± 3.1
	Stress	4.1 ± 2.3	5.1 ± 2.5***
	Weight/health concern	6.8 ± 2.2	6.7 ± 2.2
Obesity	Hunger	4.1 ± 2.4	3.7 ± 2.9**
	Stress	3.8 ± 2.4	4.1 ± 2.5
	Weight/health concern	6.7 ± 2.3	7.3 ± 2.3***

Note: Ratings of motivational state before and after viewing the four categories of photographs (neutral, food, stressor and obesity). Data expressed as mean ± standard deviation. $^{**}p < .01$, $^{***}p < .001$; significant differences for comparisons between before and after viewing the pictures for each motivational dimension.

($ps < .001$). The distribution of supertasters, tasters and non-tasters did not differ between bitter conditions (≈10/status/bitter condition) (highest $\chi^2 = 14.89$, $p = .25$). In terms of bitter perception of food solutions, the mean values of $S_{I_{max}}$ are shown in Table 2. Analysis revealed a main effect of Solution ($F[1, 171] = 58.40$, $p < .001$, $\eta^2 = .05$), with a higher $S_{I_{max}}$ for chocolate than for beer ($ps < .05$). No other Bitter condition effect or interaction approached significance (highest $F[1, 57] = 1.19$, $p = .28$).

Bitter likers vs. dislikers

Concerning the first hypothesis, separate ANOVAs revealed a main effect of Bitter condition on hedonic ($F[1, 57] = 12.93$, $p < .001$, $\eta^2 = .18$) and incentive ratings ($F[1, 57] = 14.15$, $p < .001$, $\eta^2 = .19$). A main effect of Solution on hedonic ($F[3, 171] = 45.10$, $p < .001$, $\eta^2 = .44$), incentive ($F[3, 171] = 42.26$, $p < .001$, $\eta^2 = .44$) and familiarity ratings ($F[3, 171] = 11.61$, $p < .001$, $\eta^2 = .17$) was also observed. In each of these analyses, no other effects or interactions were significant [highest $F[3, 171] = 2.12$, $p = .10$]. As illustrated in Fig. 1, bitter likers liked and wanted to drink bitter solutions more than dislikers, but no differences in familiarity were found between groups. Upon examination of the main effect of Solution, beer and grapefruit were more liked and desired than coffee and chocolate, while grapefruit was rated as more familiar compared to the other solutions ($ps < .05$). Mean hedonic and incentive ratings were 2.8 and 2.2 for coffee, 4.7 and 3.8 for beer, 2.4 and 2.0 for chocolate, and 6.0 and 5.3 for grapefruit. Mean familiarity ratings are shown in Table 2.

In terms of facial expressions, the mean changes from baseline intensity for disgust and happiness were .06 and .006 for dislikers, and .023 and .001 for likers. Analysis of disgust revealed a marginally significant main effect of Bitter condition ($F[1, 57] = 3.39$, $p = .06$, $\eta^2 = .05$), with dislikers producing greater reactions of disgust than likers, and a main effect of Solution ($F[3, 171] = 8.75$, $p < .01$, $\eta^2 = .13$). No other effects or interactions were significant (all $Fs < 1$). Concerning the effect of Solution, chocolate produced a higher increase in disgust reactions (.1) compared to grapefruit (.001) ($p < .05$).

In terms of parameters for instrumental behaviour (see Fig. 2), a significant Bitter condition × Solution interaction was found in RT ($F[3, 171] = 3.11$, $p < .05$, $\eta^2 = .05$), and a main effect of Solution ($F[3, 171] = 11.36$, $p < .001$, $\eta^2 = .17$) and a marginally significant main effect of Bitter condition ($F[1, 57] = 3.40$, $p = .06$, $\eta^2 = .05$) in AW. No other main effects or interactions approached significance (all $Fs < 1$). As illustrated in Fig. 2(A and B), likers showed a higher response time for beer and lower water consumption in general compared to dislikers ($ps < .05$). On the other hand, water intake was significantly less for beer (18.1 g) than for chocolate (33.2 g) ($p < .01$).

Responses to bitter taste under hunger, stress and weight/health concern

Concerning the second hypothesis, separate ANCOVAs revealed no significant main effect of Bitter condition, Picture category or Solution, or interactions among these factors, either on hedonic and incentive ratings or on happiness facial expression, RT and $S_{I_{max}}$ (highest $F[2, 106] = 3.00$, $p = .09$). Fig. 3 shows average hedonic (1A–1D) and incentive (2A–2D) ratings for both bitter conditions after the food, stressor and obesity pictures. Average data (collapsed by Bitter condition and Picture category) for the change in happiness expression intensity, RT and $S_{I_{max}}$, respectively, were: .010, 57.2 and 66.7 for coffee, .015, 65.0 and 36.4 for beer, .027, 52.4 and 66.6 for chocolate, and .029, 72.0 and 45.4 for grapefruit.

The change in disgust reaction from baseline did reveal a significant Bitter condition × Picture category × Solution interaction ($F[6, 318] = 2.30$, $p = .05$, $\eta^2 = .04$). Post-hoc analysis showed that in likers the intensity of disgust after tasting chocolate increased between exposure to food and to obesity pictures (Fig. 3, 3C), and that under the effect of stress pictures they displayed a greater reduction in disgust to coffee than dislikers (Fig. 3, 3A) ($ps < .05$). Furthermore, in likers obesity pictures elicited higher disgust reactions to chocolate (.09) compared with coffee (.007), beer (.001) and grapefruit (−.01) ($ps < .05$). No other pairwise comparisons showed significant differences.

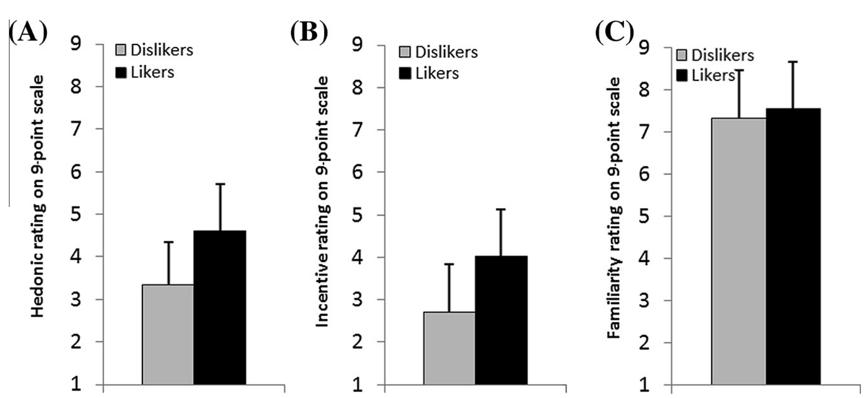

Fig. 1. Hedonic (A), incentive (B) and familiarity (C) ratings for food solutions given by bitter dislikers and likers after viewing neutral pictures. Data expressed as geometric mean ± SEM.

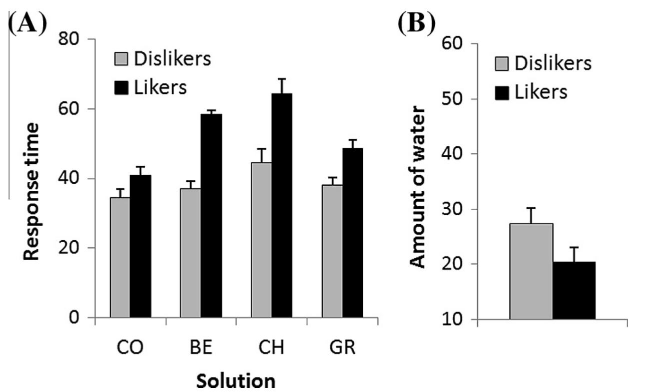

Fig. 2. Response time in seconds (A) and amount of water consumed in grams (B) relating to the instrumental behaviour of rinsing the mouth with water after viewing neutral pictures. Data of response time expressed as geometric mean ± SEM; data of amount of water expressed as mean ± SEM.

Analysis of AW showed a significant Bitter condition × Picture category × Solution interaction ($F[6, 318] = 2.40$, $p < .05$, $\eta^2 = .04$). Post-hoc analysis revealed that likers increased the amount of water used after tasting chocolate between exposure to the food and to the obesity pictures, and there was higher water consumption in likers than in dislikers after tasting chocolate under the effect of the obesity pictures ($ps < .05$; Fig. 3, 4C). No other pairwise comparisons showed significant differences.

Discussion

In order to explore the reversal of innate rejection of the unpleasant properties of bitter tastes, we examined whether the impact of acquired hedonic and incentive value is evident in a comparison of those who report liking vs. not liking bitter foods. In addition, whether motivational factors influence the preference for bitter tastes was assessed using picture-based inductions. The present research confirmed that, after viewing neutral pictures (control condition), the unreinforced bitter tastes elicited more positive hedonic responses (higher hedonic ratings and less intense disgust reactions) and greater incentive (higher incentive ratings, slower time responses of rinsing and lower water consumption) in likers compared with dislikers. Together with the absence of bitter group differences in taste familiarity and intensity of bitter taste perception (PROP and food solutions), these findings appear to support our first hypothesis: acquired affective reactions and incentive properties are involved in the preference for bitter tastes. Moreover, the fact that likers were as sensitive to bitterness as dislikers is consistent with the idea that, while genetically mediated variations in bitterness perception such as PROP taster status may explain the hedonic ratings for bitter thiourea chemical compounds, these variations are not sufficient to account for acceptability of ordinary bitter foods (Mattes, 2004; Tepper et al., 2009) as those used in the present work.

Regarding the motivational states, stressor, food and obesity pictures were successful in producing subjective feelings of tension, hunger and weight/health concern, respectively. In addition, the induction of these states differentially modulated the hedonic/incentive properties of the flavours of coffee and chocolate. In particular, after statistically controlling for the hedonic/incentive differences observed between groups in the control condition, likers exhibited a further reduced disgust reaction to coffee after viewing stressor pictures compared with dislikers. Following pictures showing obesity, bitter likers increased the expression of disgust and the amount of water used to rinse the mouth after chocolate as compared to pictures showing food. Finally, after tasting chocolate following the obesity pictures, likers drank more water than dislikers, and displayed higher disgust reactions to chocolate compared with the other food solutions after presentation of the obesity pictures. An explanation for these motivational findings is that, when subjects were stressed, the flavour of coffee was perceived as more agreeable in accordance with anticipation of tension-reducing effects; and when they were worried about weight, the flavour of chocolate was perceived as more disgusting in accordance with anticipation of calories. To the extent that obesity pictures elicited hunger- and weight/health concern-related effects, it can be suggested that perception of the flavour of chocolate depended on a reduction of caloric needs, an activation of health concern over consuming too many calories or a combination of both.

Unlike the single earlier study that examined whether facial affective reactions to bitter drinks are influenced by psychological states (emotions: joy and sadness induced using film clips; Greimel, Macht, Krumhuber, & Ellgring, 2006), we did find an impact of stress and hunger/weight concern on the expression of disgust. Use of bitter stimuli without postingestive consequences (like quinine) and emotional but not motivational manipulation may explain the dissimilar results. It is also interesting to remark that stress modified the response to coffee but not to beer or chocolate. In contrast to the tension-reduction theory of alcohol drinking (Greeley & Oei, 1999) and models of stress-induced eating (Greeno & Wing, 1994; Torres & Nowson, 2007), a tendency toward the flavour associated with high-levels of caffeine rather than alcohol (beer) or calories/theobromine (chocolate) was detected in healthy subjects after viewing pictures of physical stressors (e.g. heavy traffic, pollution), possibly because of the positive effects of coffee on physiological responses to mental stress (e.g. Sudano et al., 2005). Surprisingly, no additional hedonic/incentive changes were observed for beer throughout the motivational states of hunger, stress and weight concern when the differences between groups after viewing neutral pictures were statistically controlled. Nevertheless, the fact that alcohol reduces some types of tension (e.g. interpersonal fears) but not others (e.g. fear of physical pain) (Higgins & Marlatt, 1975) cannot be disregarded. Therefore, although our motivational manipulation covered the most psychometrically validated motives related to food choice and eating, other incentives presumed to underlie bitter preferences for alcohol such as achieving social rewards and avoiding social rejection (Cooper, 1994) remain unexplored.

The low hedonic and incentive ratings (ratings <5, except for grapefruit), as well as the lack of positive facial expressions through different states, should be noted at this point. These data, despite the favourable motivational modulation of the hedonic/incentive properties of coffee and chocolate, do not seem to support our second hypothesis: bitter preferences are led by hunger-reducing, tension-reducing or weight control-enhancing properties and are expressed by relevant motivational states. This contrasts with the results of animal studies, in which preference ratios for an unpleasant taste can be readily observed, e.g. when the nutritional consequences associated with the taste are relevant to a pronounced state of hunger (González, García-Burgos, de Brugada, & Gil, 2010). Accordingly, it could be argued that the moderate shifts towards coffee and chocolate may reflect insufficient intensity of the motivational states induced by static pictures to overcome the innate rejection of bitter tastes. This possibility is suggested from observations that the expression of food preferences/choices depends on the level of the internal state (cf. Gibson & Brunstrom, 2007) and that laboratory stressors/negative emotions are not equally effective in inducing ecologically relevant states, for instance during stress inductions in alcohol research (cf. Suzanne & Bacon, 2013). Another possibility is that the violation of expectations for the tested solutions overshadowed the bitter preferences. It has been pointed out that any difference between flavour

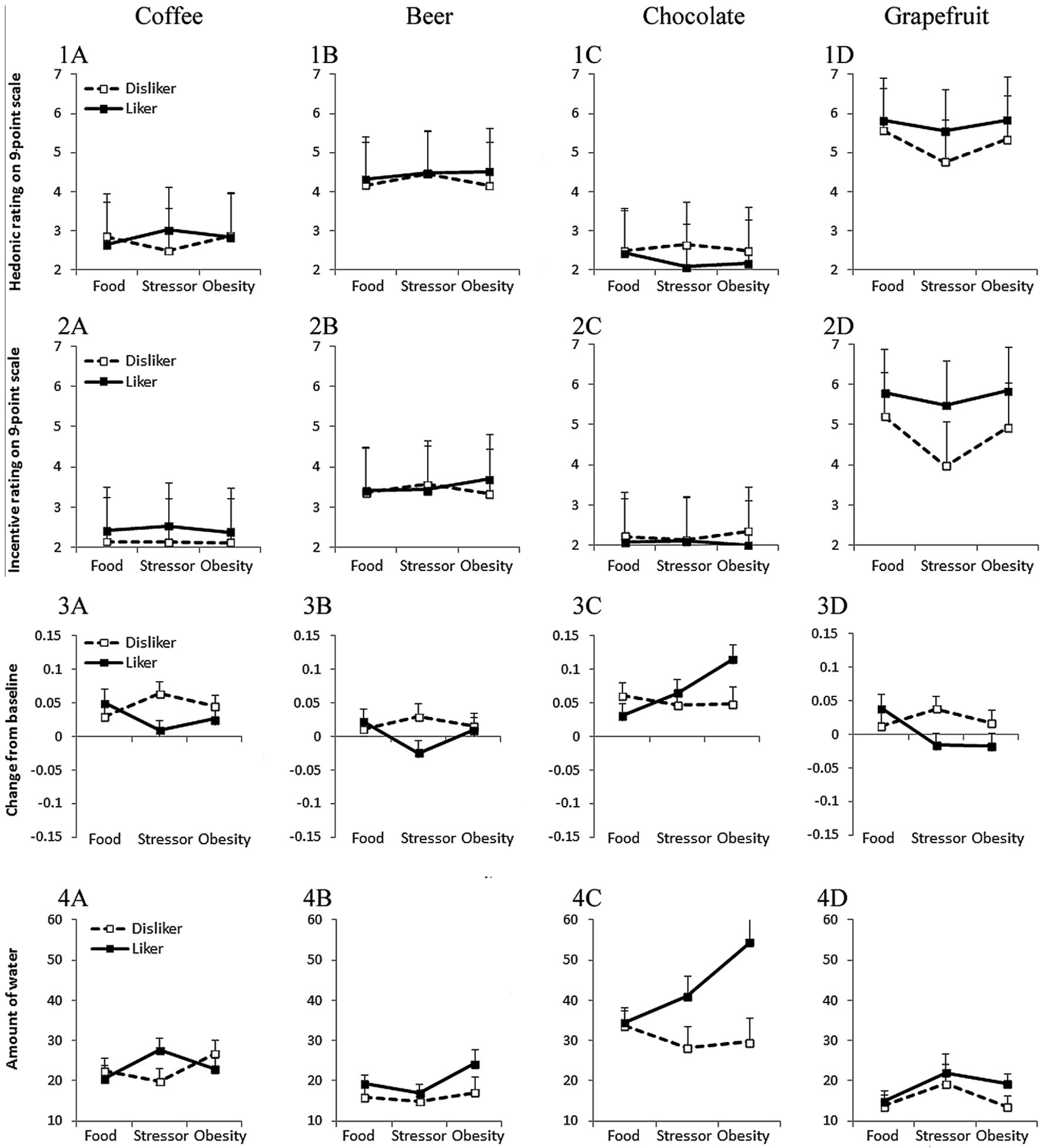

Fig. 3. Hedonic (1) and incentive (2) ratings, change in intensity of disgust from baseline (3) and amount of water in grams (4) used for the coffee (A), beer (B), chocolate (C) and grapefruit (D) solutions after viewing food, stressor and obesity pictures. Hedonic and incentive ratings expressed as geometric mean ± SEM; intensity of disgust and amount of water expressed as mean ± SEM.

perception and flavour memory results in overstated aversion and rejection (Stevenson, 2009; Yeomans, Chambers, Blumenthal, & Blake, 2008; Zellner, Stewart, Rozin, & Brown, 1988), which would have minimised the expression of preferences for the bitter tastes. In fact, the pleasant aromas reported for the sugar-free chocolate, alcohol-free beer and sugar-free decaffeinated coffee before tasting, as well as moderate familiarity ratings (<7.6, except for grapefruit) compared with the high intake of these foods reported in the food frequency questionnaires (data not shown), suggest that participants found the flavours delivered in extinction conditions somewhat different from the expected flavours.

The high hedonic, incentive and familiarity ratings, absence of disgust reactions and stability of the implicit and explicit measures across motivational states for grapefruit in bitter likers should also be mentioned, suggesting a preference based on the positive sensory characteristics rather than on post-ingestive consequences.

Indeed, in this study, relevance of the sensory properties of food solutions on the desire to eat was supported by a significant correlation between the incentive ratings and $S_{I_{max}}$ ($r = -.366$, $p < .001$; data of the motivational states collapsed). Taking into account the moderate changes induced by our motivational manipulation, further inputs in the form of additional pleasant tastes/odours may be required to completely overcome the innate rejection of bitter tastes. In such case, both the addition of substances to mask/remove bitterness or to improve the sensory appeal and an affective/incentive upshift might be sufficient to explain preferences for bitter-tasting foods in the real word, especially when the size of the hedonic change needed to make them as liked is often smaller (Zellner, 1991).

But how could the differences observed in likers vs. dislikes during neutral or other motivational states be explained in terms of mechanisms? While evidence strongly indicated that the enhanced hedonic and incentive responses were not limited to an attenuated sensory sensitivity (see 3.2 Section above), an attenuated hedonic sensitivity (i.e. ability to discriminate differences in liking/disliking) toward the bitter taste quality should be considered. In fact, given that hedonic processing intervenes between taste perception and food preferences (Drewnowski, 1997), a reduced affective reaction to the same taste qualities in bitter likers could explain to some extent both the reduced aversive response (disgust) and the lower desire to avoid the unpleasant-tasting solutions. Although the design of the present study did not permit resolution of this issue, this interpretation does not seem sufficient to explain the specific variations in hedonic responses to flavours across motivational states as such attenuated hedonic sensitivity should be observed independent of motivational states. In a similar way, the mere exposure explanation appears to be flawed as the expression of the exposure-related positive shifts should consistently overcome the motivational context changes on the basis of the high robustness and stability of this effect (see Bornstein, 1989), even when exposure takes place in unpleasant contexts (Saegert, Swap, & Zajonc, 1973). In addition, as pointed out by Zajonc, Markus, and Wilson (1974), the conditions of an exclusive mere exposure explanation for the results are not satisfied in the present research since the bitter tastes evaluated here were accompanied by pleasurable consequences in the real world (e.g. calories or alcohol; according to the FFQ and DHQ, data not shown), allowing for the formation of pleasant associative bonds. In this sense, some degree of liking for bitter tastes would be acquired through flavour-associated learning (Mattes, 1994; Zellner, 1991). Even more important, the presence of motivational states enhancing the desire for specific bitter tastes according to their reinforcing properties and consequently regulating instrumental avoidance behaviours (e.g. the amount of water for rinsing) supports the idea that the acquired hedonic/incentive value would be rather associative (cf. Dickinson & Balleine, 1995; Dickinson & Balleine, 2002, for more details on motivational control of instrumental action).

In conclusion, and despite potential limitations to generalise our results to the percentile range of 40–60 because of our use of an *extreme groups* strategy, this study highlighted not only the implication of acquired affective and motivational components in reversal of the predisposition to reject bitter tastes but also that the expression of preferences is not stable but modulated. Furthermore, for the first time it has been demonstrated that the variations in liking and willingness to consume bitter foods can be triggered by motivational states in humans. However, the motivational manipulation did not completely suppress the aversive and avoidance responses to coffee, chocolate and beer, probably due to either the violation of the flavours expectations or the low intensity of the motivational modulation in order to overcome the robust evolutionary rejection responses to bitter tastes in defending the body against dietary danger and toxicity. Since the modulation of the reward value of the flavour of food by motivational states is one important way in which eating behaviour is controlled, the present data contributes to the understanding of the mechanisms behind the ingestion of bitter substances. Given the increasing incidence of obesity, additional research is needed to determine the mechanisms that control healthy food selection.

Authors' contributions

The authors contributed equally to this article.

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References

Berridge, K. C., & Robinson, T. E. (1998). What is the role of dopamine in reward: Hedonic impact, reward learning, or incentive salience? *Brain Research Reviews, 28*, 309–369.
Berridge, K. C., & Robinson, T. E. (2003). Parsing reward. *Trends in Neurosciences, 26*, 507–513.
Bornstein, R. F. (1989). Exposure and affect: Overview and meta-analysis of research, 1968–1987. *Psychological Bulletin, 106*, 265–289.
Capaldi, E. D., & Privitera, G. J. (2008). Decreasing dislike for sour and bitter in children and adults. *Appetite, 50*, 139–145.
Conway, T. L., Vickers, R. R., Ward, H. W., & Rahe, R. H. (1981). Occupational stress and variation in cigarette, coffee, and alcohol consumption. *Journal of Health and Social Behavior, 22*, 155–165.
Cooney, N. L., Litt, M. D., Morse, P. A., Bauer, L. O., & Gaupp, L. (1997). Alcohol cue reactivity, negative-mood reactivity, and relapse in treated alcoholic men. *Journal of Abnormal Psychology, 106*, 243–250.
Cooper, M. L. (1994). Motivations for alcohol use among adolescents: Development and validation of a four-factor-model. *Psychological Assessment, 6*, 117–128.
D'Amato, M. R. (1970). *Experimental psychology: Methodology, psychophysics, and learning*. New York: McGraw-Hill.
Dan-Glauser, E. S., & Scherer, K. R. (2011). The Geneva Affective Picture Database (GAPED): A new 730 picture database focusing on valence and normative significance. *Behavior Research Methods, 43*, 468–477.
Dickinson, A., & Balleine, B. (1995). Motivational control of instrumental action. *Current Directions in Psychological Science, 4*, 162–167.
Dickinson, A., & Balleine, B. (2002). The role of learning in the operation of motivational systems. In H. Pashler & R. Gallistel (Eds.), *Stevens' handbook of experimental psychology* (pp. 497–533). New York: Wiley.
Drewnowski, A. (1997). Taste preferences and food intake. *Annual Review of Nutrition, 17*, 237–253.
Drewnowski, A., & Gomez-Carneros, C. (2000). Bitter taste, phytonutrients, and the consumer: A review. *The American Journal of Clinical Nutrition, 72*, 1424–1435.
Drewnowski, A., Henderson, S. A., & Shore, A. B. (1997). Genetic sensitivity to 6-*n*-propylthiouracil (PROP) and hedonic responses to bitter and sweet tastes. *Chemical Senses, 22*, 27–33.
Fouquereau, E., Fernandez, A., Mullet, E., & Sorum, P. C. (2003). Stress and the urge to drink. *Addictive Behaviors, 28*, 669–685.
Galmarini, M. V., Zamora, M. C., & Chirife, J. (2009). Gustatory reaction time and time intensity measurements of trehalose and sucrose solutions and their mixtures. *Journal of Sensory Studies, 24*, 166–181.
Garcia-Burgos, D., & Zamora, M. C. (2013). Facial affective reactions to bitter-tasting foods and body mass index in adults. *Appetite, 71*, 178–186.
Gaudette, N. J., & Pickering, G. J. (2013). Modifying bitterness in functional food systems. *Critical Reviews in Food Science and Nutrition, 53*, 464–481.
Gibson, E. L., & Brunstrom, J. M. (2007). Learned influences on appetite, food choice and intake: Evidence in human beings. In T. C. Kirkham & S. J. Cooper (Eds.), *Appetite and body weight: Integrative systems and the development of anti-obesity drugs* (pp. 271–300). Billington, MA: Academic Press.
González, F., García-Burgos, D., de Brugada, I., & Gil, M. (2010). Learned preference for a hedonically negative flavor is observed after pairings with positive post-ingestion consequences rather than with a palatable flavor. *Learning and Motivation, 41*, 141–149.
Greeley, J., & Oei, T. (1999). Alcohol and tension reduction. In K. Leonard & H. T. Blane (Eds.), *Psychological theories of drinking and alcoholism* (2nd ed., pp. 14–53). New York: Guilford Press.
Greeno, C. G., & Wing, R. R. (1994). Stress-induced eating. *Psychological Bulletin, 115*, 444–464.
Greimel, E., Macht, M., Krumhuber, E., & Ellgring, H. (2006). Facial and affective reactions to tastes and their modulation by sadness and joy. *Physiology & Behavior, 89*, 261–269.
He, K., Hu, F. B., Colditz, G. A., Manson, J. E., Willett, W. C., & Liu, S. (2004). Changes in intake of fruits and vegetables in relation to risk of obesity and weight gain among middle-aged women. *International Journal of Obesity, 28*, 1569–1574.
Higgins, R. L., & Marlatt, G. A. (1975). Fear of interpersonal evaluation as a determinant of alcohol consumption in male social drinkers. *Journal of Abnormal Psychology, 84*, 644–651.
Jáuregui-Lobera, I., & Bolaños Ríos, P. (2011). What motivates the consumer's food choice? *Nutrición Hospitalaria, 26*, 1313–1321.
Kern, D. L., McPhee, L., Fisher, J., Johnson, S., & Birch, L. L. (1993). The postingestive consequences of fat condition preferences for flavors associated with high dietary fat. *Physiology & Behavior, 54*, 71–76.
Lahti-Koski, M., Pietinen, P., Heliövaara, M., & Vartiainen, E. (2002). Associations of body mass index and obesity with physical activity, food choices, alcohol intake, and smoking in the 1982–1997 FINRISK Studies. *The American Journal of Clinical Nutrition, 75*, 809–817.
Mason, B. J., Light, J. M., Escher, T., & Drobes, D. J. (2008). Effect of positive and negative affective stimuli and beverage cues on measures of craving in non treatment-seeking alcoholics. *Psychopharmacology, 200*, 141–150.

Mattes, R. D. (1994). Influences on acceptance of bitter foods and beverages. *Physiology & Behavior, 56*, 1229–1236.

Mattes, R. D. (2004). 6-*n*-Propylthiouracil taster status: Dietary modifier, marker or misleader? In J. Prescott & B. J. Tepper (Eds.), *Genetic variation in taste sensitivity* (pp. 229–250). New York: Marcel Dekker Inc.

Mobini, S., Chambers, L., & Yeomans, M. R. (2007). Effects of hunger state on flavour pleasantness conditioning at home: Flavour–nutrient learning vs. flavour–flavour learning. *Appetite, 48*, 20–28.

Renner, B., Sproesser, G., Strohbach, S., & Schupp, H. T. (2012). Why we eat what we eat. The Eating Motivation Survey (TEMS). *Appetite, 59*, 117–128.

Richardson, N. J., Rogers, P. J., & Elliman, N. A. (1996). Conditioned flavour preferences reinforced by caffeine consumed after lunch. *Physiology & Behavior, 60*, 257–263.

Rogers, P. J., Richardson, N. J., & Elliman, N. A. (1995). Overnight caffeine abstinence and negative reinforcement of preference for caffeine-containing drinks. *Psychopharmacology, 120*, 457–462.

Rozin, P., & Vollmecke, T. A. (1986). Food likes and dislikes. *Annual Review of Nutrition, 6*, 433–456.

Saegert, S., Swap, W., & Zajonc, R. B. (1973). Exposure, context, and interpersonal attraction. *Journal of Personality and Social Psychology, 25*, 234–242.

Schüssler, P., Kluge, M., Yassouridis, A., Dresler, M., Uhr, M., & Steiger, A. (2012). Ghrelin levels increase after pictures showing food. *Obesity, 20*, 1212–1217.

Smit, H. J., & Blackburn, R. J. (2005). Reinforcing effects of caffeine and theobromine as found in chocolate. *Psychopharmacology, 181*, 101–106.

Stein, L. J., Nagai, H., Nakagawa, M., & Beauchamp, G. K. (2003). Effects of repeated exposure and health-related information on hedonic evaluation and acceptance of a bitter beverage. *Appetite, 40*, 119–129.

Steiner, J. E. (1979). Human facial expressions in response to taste and smell stimulation. *Advances in Child Development and Behavior, 13*, 257–295.

Stevenson, R. J. (2009). *The psychology of flavour*. Oxford: Oxford University Press.

Sudano, I., Spieker, L., Binggeli, C., Ruschitzka, F., Lüscher, T. F., Noll, G., & Corti, R. (2005). Coffee blunts mental stress-induced blood pressure increase in habitual but not in nonhabitual coffee drinkers. *Hypertension, 46*, 521–526.

Sun, Y. H. C. (2008). Health concern, food choice motives, and attitudes toward healthy eating: The mediating role of food choice motives. *Appetite, 51*, 42–49.

Suzanne, T., & Bacon, A. (2013). Stress and affective inductions in addiction research. In J. MacKillop & H. De Wit (Eds.), *Handbook of addiction psychopharmacology* (pp. 411–434). New York: Wiley-Blackwell.

Tepper, B. J., White, E. A., Koelliker, Y., Lanzara, C., d'Adamo, P., & Gasparini, P. (2009). Genetic variation in taste sensitivity to 6-*n*-propylthiouracil and its relationship to taste perception and food selection. *Annals of the New York Academy of Sciences, 1170*, 126–139.

Tinley, E. M., Durlach, P. J., & Yeomans, M. R. (2004). How habitual caffeine consumption and dose influence flavour preference conditioning with caffeine. *Physiology & Behavior, 82*, 317–324.

Torres, S. J., & Nowson, C. A. (2007). Relationship between stress, eating behavior, and obesity. *Nutrition, 23*, 887–894.

USDA database (2014). U.S. Department of Agriculture, Agricultural Research Service, National Agricultural Library. *National nutrient database for standard reference, release 25*. Beltsville, MD: Beltsville Human Nutrition Research Center, Food Surveys Research Group. Available from: http://ndb.nal.usda.gov/ndb/foods/list.

Yeoman, M. R., Jackson, A., Lee, M. D., Nesic, J., & Durlach, P. J. (2000). Expression of flavour preferences conditioned by caffeine is dependent on caffeine deprivation state. *Psychopharmacology, 150*, 208–215.

Yeomans, M. R., Chambers, L., Blumenthal, H., & Blake, A. (2008). The role of expectancy in sensory and hedonic evaluation: The case of smoked salmon ice-cream. *Food Quality and Preference, 19*, 565–573.

Yeomans, M. R., & Mobini, S. (2006). Hunger alters the expression of acquired hedonic but not sensory qualities of food-paired odors in humans. *Journal of Experimental Psychology: Animal Behavior Processes, 32*, 460–466.

Yeomans, M. R., Mobini, S., & Chambers, L. (2007). Additive effects of flavour–caffeine and flavour–flavour pairings on liking for the smell and flavour of a novel drink. *Physiology & Behavior, 92*, 831–839.

Yeomans, M. R. (2006). The role of learning in development of food preferences. In R. Shepherd & M. Raats (Eds.), *The psychology of food choice* (pp. 93–112). Wallingford: CABI Publishing.

Yeomans, M. R., Spetch, H., & Rogers, P. J. (1998). Conditioned flavor preference negatively reinforced by caffeine in human volunteers. *Psychopharmacology, 137*, 401–409.

Zajonc, R. B., Markus, H., & Wilson, W. R. (1974). Exposure effects and associative learning. *Journal of Experimental Social Psychology, 10*, 248–263.

Zellner, D. A. (1991). How foods get to be liked: Some general mechanisms and some special cases. In R. C. Bolles (Ed.), *The hedonics of taste* (pp. 199–217). Hillside, New Jersey: Lawrence Erlbaum Associates.

Zellner, D. A., Stewart, W. F., Rozin, P., & Brown, J. M. (1988). Effect of temperature and expectations on liking for beverages. *Physiology & Behavior, 44*, 61–68.