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# Skin conductance responses to oral stimuli: The role of taste quality and intensity, and personality traits

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ABSTRACT

Measuring emotional responses to tastes and foods, using both self-reports and also implicit and physiological measurements is gaining attention. Among physiological measurements, skin conductance response (SCR) is one the most commonly used indicators of emotional activation but it has been rarely applied to taste and other oral stimuli and its interpretation is not yet clear. Furthermore, the effect of individual differences in SCR to tastes has been rarely taken into account. To address these issues, SCR to bitter, astringent, and sweet samples presented both at weak/moderate and moderate/strong intensity was recorded while eighty Italians, selected based on PROP (6-n-propylthiouracil) status (only Medium-Tasters), performed an implicit affective test. Samples were presented blind in aqueous solutions monadically in triplicate. Subjects (Ss) were asked to taste a sample, then a neutral face was briefly presented on a screen, and Ss were asked to indicate if they trusted the face (yes/no) and how much (on a 9-point Scale). Data on Ss' psychological traits (anxiety, sensation seeking, food neophobia, emotional stability) was also collected. Two clusters were identified based individual SCR. These clusters differed in their SCR mainly to strong bitterness, and partially to astringency, while they did not differ for their response to the sweet samples. The *High bitter responders* were more anxious and neurotic than Low bitter responders. For this cluster higher intensities induced higher SCR, but this was not found in the *Low bitter responders* cluster that tended to have higher SCR to the least intense samples. No differences in the implicit affective responses to samples were found between clusters. These results indicate that SCR to tastes reflect mainly different sources of arousal, such as novelty/surprisingness, quality and intensity of the stimuli, and this may change at an individual level. This suggests that measurement of SC can contribute to a better understanding of individual differences in taste and oral experience and could provide a link between taste responsiveness and sympathetic nervous system activity.

## 1. Introduction

In the last decade, there has been an increasing interest in measuring emotional responses to tastes and foods, using both self-reports and also implicit and physiological measurements. Studies using explicit ratings have shown that products may elicit different degrees of the same emotion but also are able to elicit different emotions, thus contributing to a better understanding of food acceptability (Cardello & Jaeger, 2021; Schouteten, 2021). When using non-explicit methods such as those measuring autonomic nervous system activity (e.g. heart rate and skin conductance) or using implicit methods to assess emotions in response to foods, findings have been less clear and generally more difficult to interpret (de Wijk & Boesveldt, 2016).

According to the theory of constructed emotions, a multimodal measurement approach has been recommended as a way of studying emotional responses, since different modalities (such as exteroceptive perception, interoception, core affect, attention, categorization, executive processing, episodic memory, action, language, reasoning, and so forth) carry unique information about an instance of an emotion (Barrett & Westlin, 2021; Wilson-Mendenhall et al., 2011). One approach has been to augment explicit or non-explicit emotion measures with measurement of physiological signals that are emotionally reactive. Skin

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conductance levels (SCL) and responses (SCR) are some among the most commonly used measures of Autonomic Nervous System (ANS) activation and provide a direct and undiluted representation of the sympathetic activity (Dawson et al., 2016). While subtle and low-level changes in emotion can affect SC, such responses have low specificity, as changes in SC are related to many mental states (Mendes, 2016). For example, emotions with quite different valences, e.g., anger and enthusiasm, can increase SC (Kreibig, 2010; Shiota et al., 2011). As a result, it has been suggested that as SCR primarily indicate broad mental states such as cognitive demand, saliency, general arousal, or effort, and thus the determination of the psychological meaning of any particular SCR is dependent on a well-controlled stimulus situation (Dawson et al., 2016).

While there is some evidence that SCR duration responds to emotional valence (Cacioppo et al., 2000), a variety of studies have shown that SCL increases systematically and linearly according to the rated arousal of emotional stimuli, independently of the stimulus valence and the specific emotion induced (Bradley & Lang, 2000; Lang et al., 1993). However, skin conductance does not reflect only changes in arousal as it is responsive to numerous physical conditions including temperature, humidity and to skin hydration, and to many mental states including the level of familiarity/novelty of the stimulus (Quigley, Lindquist, & Barrett, 2014). In fact, it has been pointed out that the sympathetic skin response (SCR) can be triggered by nearly any new, surprising, potentially significant, distinct stimulus present in the surroundings, and also by the absence of an expected stimulus (Siddle, 1991, Dawson et al., 2016).

While skin conductance responses have been extensively studied in response to visual, auditory and smell stimuli, their measurement in response to oral chemosensory stimuli has been limited. Some studies measuring skin conductance in response to tastes have suggested that these responses reflected the taste's hedonic valence. Rousmans and colleagues (2000), for example, found that hedonically-positive sweetness induced lower skin conductance responses than bitter, sour and salty tastes, the latter taste being less pleasant.

However, a later study by the same group failed to confirm these findings as no difference in SCR was found in response to sweet tastes and products that were significantly different in liking (Leterme et al., 2008). One possibility, raised by these authors, is that greater habituation with sweetness might explain lower SCR. Other studies on basic tastes reported contrasting results, with some finding a significant but weak negative correlation of skin conductance with self-reported liking of the stimuli (Danner et al., 2014; Lagast et al., 2020, Verastegui-Tena et al., 2018), and others showing no relationship between liking and skin conductance (Samant et al., 2017; Samant & Seo, 2018), or reporting mixed results (de Wijk et al., 2012).

In addition, since there is evidence that SCR can be strongly dependent on subjective arousal induced by stimulus intensity or novelty (Bensafi et al., 2002, Verastegui-Tena et al., 2018), stimulus valence may be only incidentally reflected in SCR. While sweetness and bitterness are innately liked and disliked respectively, they may also differ in their arousing effect. Bitterness in fact is more alerting than sweetness and has been described as a sensory signal of potential harm (Lim & Green, 2007). Furthermore, the intensity of the stimulus should be considered, as this may also independently modulate both valence and arousal. For example, saltiness is innately liked, unless it is presented at high intensity (Hayes et al., 2010). Tasting a very bitter sample may be aversive (negative valence, high arousal), while tasting a very sweet sample may induce a low arousal positive emotion such as happiness or relaxation rather than a positive emotion associated with high arousal, such as excitement.

An important research focus in human responses to chemosensory stimuli has been the role of systematic individual differences. It is well known that individuals differ greatly in their liking for, and in their sensory perception of, taste stimuli. The most well-researched index of individual variations in taste perception has been responsiveness to the bitterness of 6-n-propylthiouracil (PROP) which has been shown to be a reliable index of overall oral sensitivity (Hayes & Keast, 2011; Tepper et al., 2017), with very high responding (super-tasters) and low responding (non-tasters) individuals to PROP bitterness each representing around 25% of the population, and around 50% reporting moderate to high bitterness (medium-tasters). Depending on PROP status, basic tastes (bitterness, salt, sour, sweet and umami) are also rated as more or less intense (Bajec & Pickering, 2008; Dinnella et al., 2018; Drewnowski et al., 1998; Hayes et al., 2008; Ly, 2001; Nolden et al., 2020; Piochi et al., 2021; Prescott et al., 2001). In addition to PROP status, individual variations in salivary protein characteristics can also influence the perception of tactile sensations like astringency (Dinnella et al., 2009, 2010). Systematic variations in taste valence, independent of intensity, are also found, with populations being divided into sweet, salty and sour relative likers and dislikers, often with one or more intermediate groups (Iatridi et al., 2019; Kim et al., 2014; Pangborn, 1970, Spinelli et al 2021) with relevant implications for food preferences.

Furthermore, individuals differ in enduring personality traits, which in turn may affect their responses to tastes and other chemosensory stimuli (odours; somatosensory qualities; flavour). Food neophobia, for example, has been associated with a heightened responses to chemosensory sensations such as pungency and astringency (Laureati et al., 2018; Spinelli et al., 2018) and to a general higher responsiveness to sensory properties (Prescott et al., 2022). Such response modulation appears to be associated with variations in the extent to which stimuli are arousing. Thus, anxiety has been associated with heightened response to tastes and olfactory stimuli (Krusemark & Li, 2012), and anxiety and high arousal have been associated with food neophobia (Galloway et al., 2003; Jaeger et al., 2021; Jaeger et al., 2023; Pliner & Hobden, 1992).

Similarly, individual differences in electrodermal activity have been linked to enduring traits, particularly those involving variations in higher central process involved in attending to and processing information (Katkin, 1975; Dawson, Schell, & Filion, 2016). In addition, positive associations have been reported between skin conductance responses and traits including state anxiety (Krusemark & Li, 2012), neuroticism (Norris et al., 2007), sensation seeking (Smith et al., 1986), novelty seeking and harm avoidance (Yoshino et al., 2005).

The primary aim of this study is to explore the sensory and affective responses to oral sensations (the basic tastes, sweetness and bitterness, and the oral tactile sensation of astringency) using skin conductance as an ANS activation index. This measure may allow us to determine the extent to which the novelty, valence and intensity of oral stimuli may influence ANS activation, individually and interactively. Based on previous findings, we hypothesised that SCR would be higher when the stimuli were novel (in an initial evaluation, compared to subsequent evaluations), and also when the stimuli were more intense. This study would also allow us to determine if there are intrinsic differences in the arousal levels of different qualities, which might be evident in interactions between valence and intensity. For example, does a strong bitterness elicit a stronger SCR than strong sweetness?

The rationale behind this study is that intensity interacts with valence in inducing arousal and thus, in its impact on the SCR. SCR effect through replicates was measured as a control for habituation and for this reason all the stimuli were presented in blind condition (without disclosing their name).

To rule out the potential impact of a well-known variation in taste phenotype, only PROP medium tasters were included in the study.

Given that research measuring autonomic nervous system responses to tastes as a function of individual differences is sparse, the second aim of this study is to explore the individual differences in SCR. We expected that individuals would differ widely in their SCR and that there are individuals who are overall more responsive. Since SCR reflect arousal, individuals should differ in their SCR to oral stimuli based on those personality traits and psychological states that reflect such variations in arousability. In particular, we expected that individuals who perceive

stimuli (particularly warning stimuli such as bitterness) more intensely due to personality traits would show higher SCR, and will report a more negative affective response to stimuli. We expected also that individuals who are more anxious, less stable emotionally, who score higher in food neophobia and lower in sensation seeking would be more electrodermally reactive.

## 2. Materials and methods

### 2.1. Subjects

SCR to tastes were recorded from 80 Italian subjects (48 women) with a mean age of 27.4 years (range from 20 to 40 years, SD = 6.3), a subsample of a larger experiment on implicit affective responses to chemosensory stimuli (Pierguidi et al., 2023). SCR data were inspected before analysis and individual outliers (defined as those with mean peak amplitudes of more than three SDs from the individual mean peak amplitude) were discarded. In total, 11 subjects (Ss) were excluded due to high noise and/or artifacts in the SCR recordings. The final sample was composed of 69 Ss (mean age 27.8 years, 41 women). All Ss underwent a screening phase in which only PROP medium taster individuals, i.e. those responding to a 3.2 mM propylthiouracil solution between "moderate" and "very strong" on a general Labelled magnitude Scale (gLMS) (Bartoshuk et al., 2004) were selected. Exclusion of PROP non-taster and supertaster individuals was aimed to avoid the effect of taste phenotype in modulating responses to basic tastes and tactile sensations (Gent & Bartoshuk, 1983; Pickering & Robert, 2006; Prescott et al., 2001). The use of medicines that could interfere with the autonomic nervous system (ANS) responses (e.g., medications to treat attention-deficit/hyperactivity disorder, insomnia, anxiety, high blood pressure, rheumatoid arthritis, epilepsy/seizures) was another reason for exclusion, and only subjects with normal or corrected to normal vision were included to avoid interferences with the implicit visual tasks. Written informed consent was obtained from all subjects in line with the General Data Protection Regulation (GDPR) 2016/679. This study was conducted according to the principles established in the Declaration of Helsinki. All subjects were compensated with a monetary reward (shopping coupon) for their participation in the study.

### 2.2. Tasting samples

Seven tasting samples, corresponding to two basic tastes (bitter and sweet) and a tactile sensation (astringency), each presented at two different concentrations (weak/moderate = Low, and moderate/strong = High), and water were employed. Details of tastants were as follows: bitterness (caffeine), low = 1.5 g/kg, high = 3 g/kg; sweetness (sucrose), low = 71.88 g/kg, high = 200 g/kg; astringency (aluminium sulphate), low = 0.8 g/kg, high = 1.6 g/kg. These concentrations were based on published psychophysical data (Feeney & Hayes, 2014; Masi et al., 2015; Monteleone et al., 2017; Yeomans et al., 2007) and preliminary tests conducted with 100 subjects to select solutions with weak/moderate (from 6 to 17 on a gLMS; Low) or moderate/strong (from 17 to 35 on a gLMS; High) rated intensity. Each sample (10 ml) was presented in a 80 ml plastic cup identified with a random three-digit code.

### 2.3. Overview of the procedure

The study took place in the Sensory Laboratory of Florence University, Italy. The experimental procedure included laboratory sessions on two different days and a preliminary online session (Fig. 1). Before participating in the lab sessions, Ss completed an online questionnaire which included information about gender, age, the food neophobia, the trait anxiety, the sensation seeking and the emotional stability scale using the platform *surveygizmo.eu*. During the first session in the lab (day 1), Ss performed an implicit task which consisted of the evaluation of the trustworthiness of neutral faces after tasting each sample with two measures (yes/no and rating scale). During this session, skin conductance responses (SCR) were continuously recorded. In the second session (day 2), sample intensities were rated. In neither session were Ss informed about the sensory quality of samples that they were tasting, which were each presented in three replicates. The order of the sample presentation was balanced in each series among Ss using a Williams Latin square design.

At the beginning of each session, Ss completed the STAI-Y (state

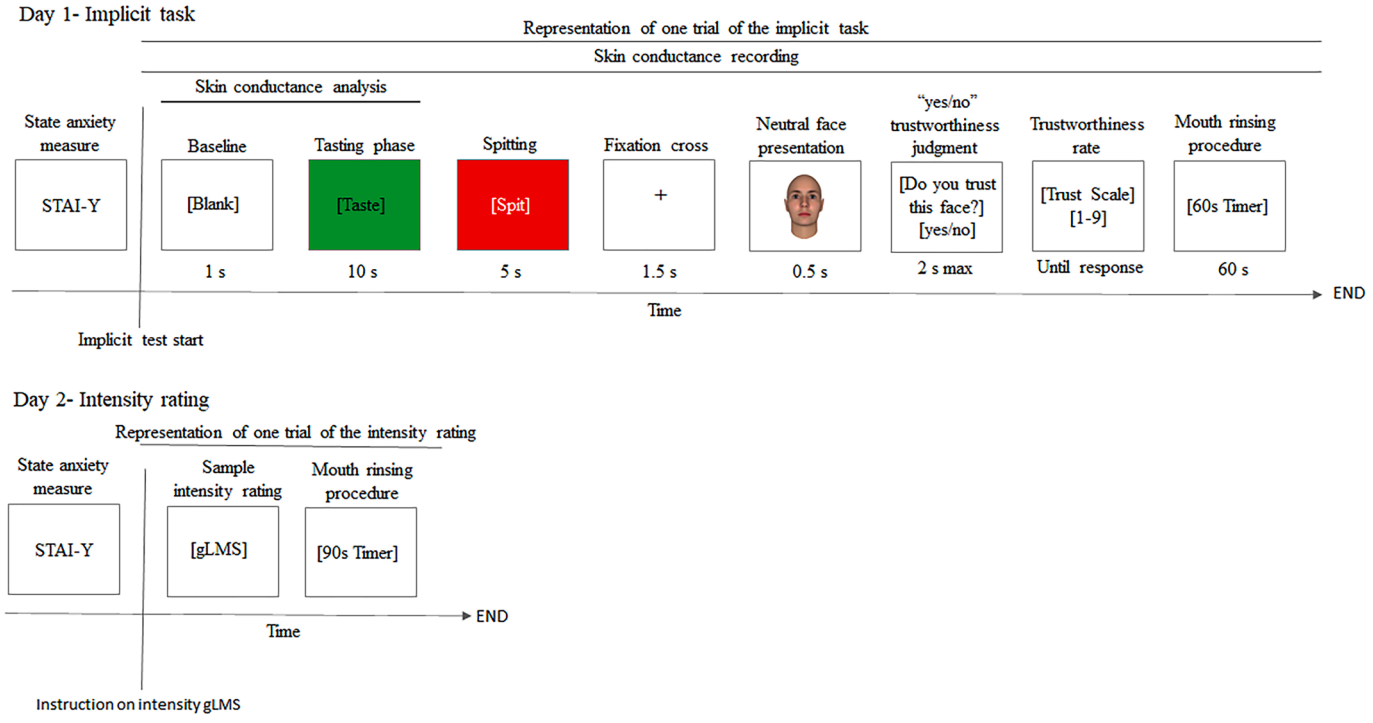


**Fig. 1.**

anxiety) questionnaire to measure anxiety experienced by subjects when they were about to start the experimental procedure. Then, in the first session, they were comfortably seated in sensory booths and the electrodes to detect SCR were attached. Following this, a blank screen was presented for 1 s during which skin conductance individual baselines were recorded, then the first tasting sample was presented. The tasting phase for each sample lasted 10 s followed by the instruction to spit the sample after 5 s. Different colours (green and red) on the computer screen signalled the tasting and spitting phases. Next, a fixation cross was displayed at the centre of the screen for 1.5 s before the presentation of a randomly selected neutral face for 0.5 s. After the face presentation, a "yes/no" trustworthiness judgment (Todorov et al., 2013) was presented on the screen for 2 s, and Ss were asked to respond as quickly as they can by pressing one of two buttons on the keyboard labelled "yes" or "no". The purpose of this task was to capture the initial response of subjects to faces and, consequently, record their reaction times. The subsequent screen asked Ss to rate how much they trusted the previously presented face. This judgment was made on a 9-point scale, ranging from 1 (not at all) to 9 (very much) (Treinen et al., 2012). This evaluation served as an additional and distinct measure to assess the influence of the priming stimulus on the perception of face trustworthiness. At the end of each trial, subject rinsed their mouth with water for 60 s. Subject were never informed that the faces were neutral. A warm-up trial was used to train subjects about the procedure. Data were collected using the E-prime software (Psychological Software Tools, Pittsburgh, PA).

In the second session, Ss were first introduced to the use of the

**Fig. 2.**

general Labelled Magnitude Scale (gLMS; Bartoshuk et al., 2004) following the procedure described in Dinnella et al., 2018, and then completed the STAI-Y (state anxiety) and evaluated the samples. Ss were instructed to taste each sample and rate the intensity using the gLMS scale. After tasting a sample, water and plain crackers were served as palate cleansers (for 90 s). Data were collected with the software Fizz (ver.2.51 B, Biosystèmes).

### 2.4. Skin conductance response (SCR) measurements

SCR were measured continuously during the first session. Electrodermal activity was recorded using a Galvanic Skin Response (GSR) device (Neulog GSR Logger Sensor NUL-217) equipped with reusable dry Ag/AgCl electrodes. Before starting the experimental procedure, electrodes were attached over the intermediate phalanges of index and middle fingers of the non-dominant hand (Fig. 2). Ss were instructed not to move this hand during the test, except during the breaks (between the evaluation of the samples). SCR measurements were recorded in micro-Siemens. Data were collected at a sampling rate of 2 Hz. Room temperature (18–20 °C) was kept constant during the recording. SCR were baseline corrected for each subject and calculated as a mean of peak amplitudes taken every 2 s during the collection window (Baseline phase = 1 s; Taste phase = 10 s). Data were pre-processed using a customized script developed with the software Matlab (Mathsworks, ver. R2818b). Furthermore, trials were visually inspected and data were removed in presence of drift factors (artifacts).

### 2.5. Visual stimuli

Twenty-one computer-generated neutral faces were selected from a freely available, validated database that includes data on emotional expression and trustworthiness by gender (Todorov et al., 2013). The rationale behind the selection of artificially-generated faces instead of real ones is that facial information provided by real faces, and in particular the trustworthiness level that they express, could be difficult to control (Dotsch & Todorov, 2012). Selected faces were balanced for gender, had a neutral level of trustworthiness and a neutral expression. They were bald, Caucasian, and were represented with a direct gaze toward the observer.

### 2.6. Anxiety and personality trait questionnaires

***State and Trait Anxiety.*** Subjects completed the State-Trait Anxiety Inventory form Y (STAI-Y) developed by Spielberger et al. (1983) in the validated Italian translation (Pedrabissi & Santinello, 1989). The STAI-Y is a psychological inventory that consists of self-report questions that measure two types of anxiety: the State Anxiety Scale asks the subjects to respond based on how they feel at that precise moment, whereas the Trait Anxiety Scale ask the subjects to respond, based on how they usually feel. Each scale was composed of 20 items on a 4-point Likert scale (1 = not at all; 4 = very much). For each subject, state and trait anxiety scores were computed by adding all the scores of each question in each respective scale. Higher scores indicated higher levels of anxiety. Items 1, 2, 5, 8, 10, 11, 15, 16, 19, and 20 (State Anxiety Scale) and items 21, 23, 26, 27, 30, 33, 34, 36 and 39 (Trait Anxiety Scale) were reverse scored.

***Sensation seeking,*** defined as the tendency to pursue new and different sensations, feelings, and experiences, was measured with the Sensation Seeking Scale (SSS) recently revised in the Zuckerman-Kuhlman-Aluja Personality Questionnaire (ZKA-PQ, Aluja et al., 2010), a new questionnaire based on the Zuckerman's original five-factor model developed to solve some limitations of the scale (see Rossier et al., 2016 for the Italian validation). The SSS factor is virtually identical to that in Zuckerman (1971) early sensation seeking scale, but the scales are improved because the items do not contain any content related to specific activities such as sex or substance abuse (e.g. alcohol). The SSS consists of 40 questions. For each subject, it is possible to obtain a global score (range 40–160) by adding all the scores of each question measured on a 4-point Likert scale (1 = strongly disagree;4 = completely agree). Items 12, 16, 20, 23, 38, and 40 were reverse scored.

***Food neophobia (FN),*** traditionally defined as the reluctance to try and eat unfamiliar foods, was quantified using the 10-statement scale developed by Pliner & Hobden (1992) and validated in Italian by Laureati et al. (2018). Individual food neophobia scores were computed as the sum of ratings given to the 10 statements, after reversing the neophilic items (using a seven-point Likert scale: disagree strongly/agree strongly). The scores ranged from 10 to 70, with higher scores corresponding to higher food neophobia.

***Emotional stability***, the opposite of neuroticism, is a fundamental personality trait that reflects being even-tempered, particularly in the face of challenges and threats. It was measured using the homonymous subscale of the Big Five Questionnaire-2 (BFQ-2) (Caprara et al., 2007) which consisted of 24 items. Responses are based on a 4-point Likert scale (from 1 = absolutely false for me to 4 = absolutely true for me). Individual scores were computed as the sum of ratings after reversing the control items (3, 15, 33, 45, 62, 63, 69, 83, 98, 104, 116, 120 of the BFQ-2 questionnaire).

A set of analyses was conducted to evaluate the factor structure and reliability of the Italian version of the State and Trait Anxiety, Sensation seeking, Food neophobia, and Emotional stability. The factor structure of each scale was investigated using Principal Component Analyses (PCA, with Varimax rotation, when more than one factor was investigated). The internal reliability of each scale was assessed with Cronbach's α (Nunnally, 1978). The factor structure was satisfactory in all the cases with few exceptions. In the emotional stability scale, item 66 was removed as it did not load satisfactorily on the factor. For the same reason, item 8 of the State Anxiety Scale was removed. In all scales, after these changes, Cronbach's α was above 0.60 which was set as the lowest acceptable limit for the satisfactory internal consistency of the measure (Bagozzi & Yi, 1988; Mohamad et al., 2015).

### 2.7. Data analysis

SCR data were analysed using a mixed ANOVA model with samples and replicates as fixed factors and subjects as random factors. The sample*replicate interaction was also calculated. In the subsequent analyses, only the SCR to the first series was considered to control for the effect of habituation (Flykt et al., 2007).

To investigate the individual differences in SCR, a PCA was conducted on individual SCR (row: samples; columns: subjects). The outputs of the analysis are summarized in two maps: a correlation loading plot, in which Ss are shown and a score plot in which samples are shown. Individual responses are represented on the map by points, which can be considered as endpoints of vectors from the origin. The direction of the vector represents the direction of increasing SCR for a given S; and the length indicates how well that individual is represented by the dimensions that are being plotted (i.e., how much variance is explained). The greater the distance of the S from the origin, the better that person's response is explained by the model (Monteleone et al., 1998). After full cross-validation, four components were indicated as optimal and retained for further analyses.

To identify groups of Ss who had different SCR for the different samples, a hierarchical clustering was performed using Ward's method (Ward, 1963) on Ss' coordinates for the first four PCA components. Agglomeration schedule and dendrogram were inspected allowing us to decide that a two-cluster solution would be optimal. Next, a K-means cluster analysis was performed (with 2 clusters). The K-means clustering partition method was selected as recommended by Wajrock et al. (2008).

To confirm that the derived consumer clusters had different patterns of SCR to basic sensations, a two-way ANOVA model (cluster and sample as factors) was employed. The interaction of cluster*sample was also

calculated. To test difference in SCR between clusters considering their trustworthiness judgement for neutral faces, a three-way ANOVA model (cluster, sample and yes/no response as factors) with interactions was employed. To test the effect of cluster membership on trustworthiness ratings for neutral faces and taste intensity, two three-way ANOVA models (cluster, samples and replicates as factors) with interactions were applied. Before analyses, trustworthiness judgments were mean centred to minimize possible effect of scale usage.

To clarify the effects of taste quality and concentration in eliciting different SCR among clusters, a three-way ANOVA model (cluster, sample quality and concentration as factors) with interactions was applied. Furthermore, to test the effect of cluster membership, sample quality and concentration and their interactions on RTs, two three-way ANOVA models were applied. The first model was performed on RTs collected when the S evaluated a face as trustworthy ("yes" response), while the second model was performed on RTs collected when the S evaluated a face as non-trustworthy ("no" response). Consistently with previous studies on RTs to facial trustworthiness, responses faster than 250 ms and slower than 1500 ms were excluded from the data analysis (Hoogeveen et al., 2016). RT data were log-transformed before analysis to reduce distribution skewness (Ratcliff, 1993). The water sample was excluded from these last analyses since it was a neutral stimulus not modulated for intensity.

The difference between the two clusters in gender, age, and personality traits were tested using one-way ANOVA models (for quantitative data) and chi-square test (for binary data). Pearson's correlation coefficients were calculated to assess linear correlations between SCR (first replicate), perceived intensity, and trustworthiness scores for neutral faces (mean centered) in the two sub-groups ($\alpha = 0.05$).

When ANOVA models were employed, post-hoc Fisher (LSD) multiple comparison tests ($\alpha = 0.05$) were carried out to determine significant differences between means. PCA was performed using Unscrambler version 11, Camo. All other statistical analyses were performed using XLSTAT software version 2020 1 (Addinsoft, Long Island, NY, USA).

## 3. Results

### 3.1. Skin conductance responses to the different oral stimuli

An effect of the replicates ($F_{(2,1427)} = 12.499$, $p < 0.0001$) and of Ss ($F_{(68,1427)} = 5.684$, $p < 0.0001$) on SCR was found, while no significant effect of sample nor of the interaction of sample and replicates were found. Specifically, SCR to the first replicate were always higher compared to the second and the third replicate, independent of the taste quality (Fig. 3), suggesting an habituation effect.

To explore individual differences in SCR, a PCA was conducted on individual SCR. This showed large variability between subjects, with many not reporting a change in SCR to tastes (Fig. 4). Four components were retained as optimal after full cross-validation.

The first component, (35% of explained variance), showed a positive correlation with low bitterness and water and a negative correlation with high bitterness. However, it is worth noting that only certain individuals demonstrated higher skin conductance response (SCR) to high bitterness compared to other sensations. The second component (20% of explained variance), showed a positive correlation with low sweetness and a negative correlation with high sweetness. The third component (16% of explained variance), showed a positive correlation with high astringency and a negative correlation with low astringency. These latter two components indicated that individuals primarily differed in their responses to samples based on concentration. Lastly, the fourth component (14% of explained variance), showed a positive correlation with high sweetness and a negative correlation with water. Two clusters differing in their patterns of SCR were identified through K-means cluster analysis (iterations = 500/convergence = 0.00001) computed on subject coordinates for the first four PCA components: Cluster 1 included 42 subjects (61%), whereas Cluster 2 consisted of 27 subjects (39%).

### 3.2. Cluster differences in skin conductance responses to oral stimuli

No significant overall effect of cluster ($p = 0.762$) on the SCR was found, but there was a significant effect of sample ($F_{(6,482)} = 3.81$, $p = 0.001$) and a significant interaction between cluster membership and sample ($F_{(6,482)} = 10.38$, $p < 0.0001$). High bitterness was found to elicit a stronger SCR compared to the other samples. However, the interaction between variable showed that Ss belonging to cluster 2 had higher SCR to high bitterness compared to cluster 1, while cluster 1 showed higher SCR to low astringency as compared to the other cluster. For cluster 2, the SCR to high bitterness was higher than the SCR response to all the stimuli. Among the other stimuli, low sweetness induced a higher SCR compared to water, but did not differ from the others. In contrast, cluster 1 had quite similar SCR to the different samples, with weak bitterness and astringency inducing a higher SCR than strong bitterness. Due to these differences in SCR, the taste clusters were identified as *Low bitter responders* (lBR; cluster 1) and *High bitter responders* (hBR; cluster 2) (see

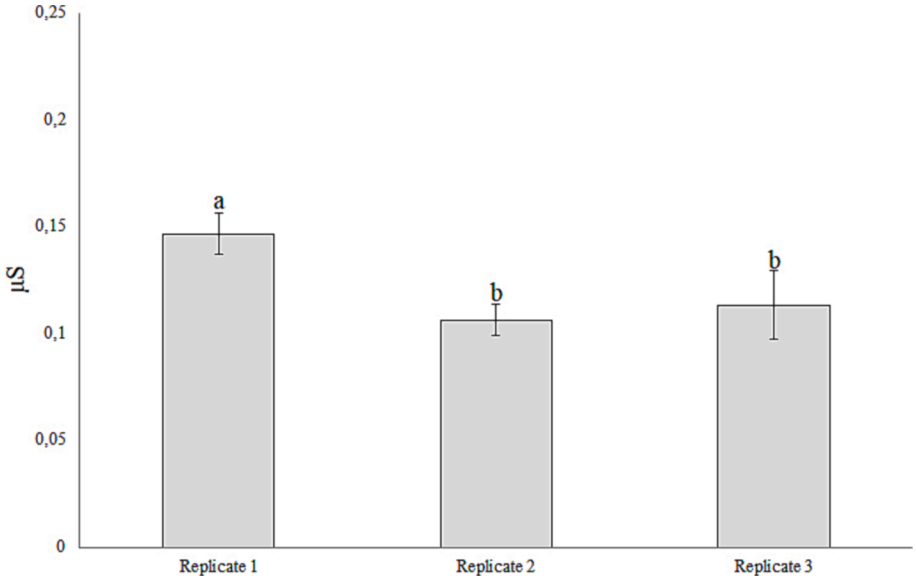


**Fig. 3.**

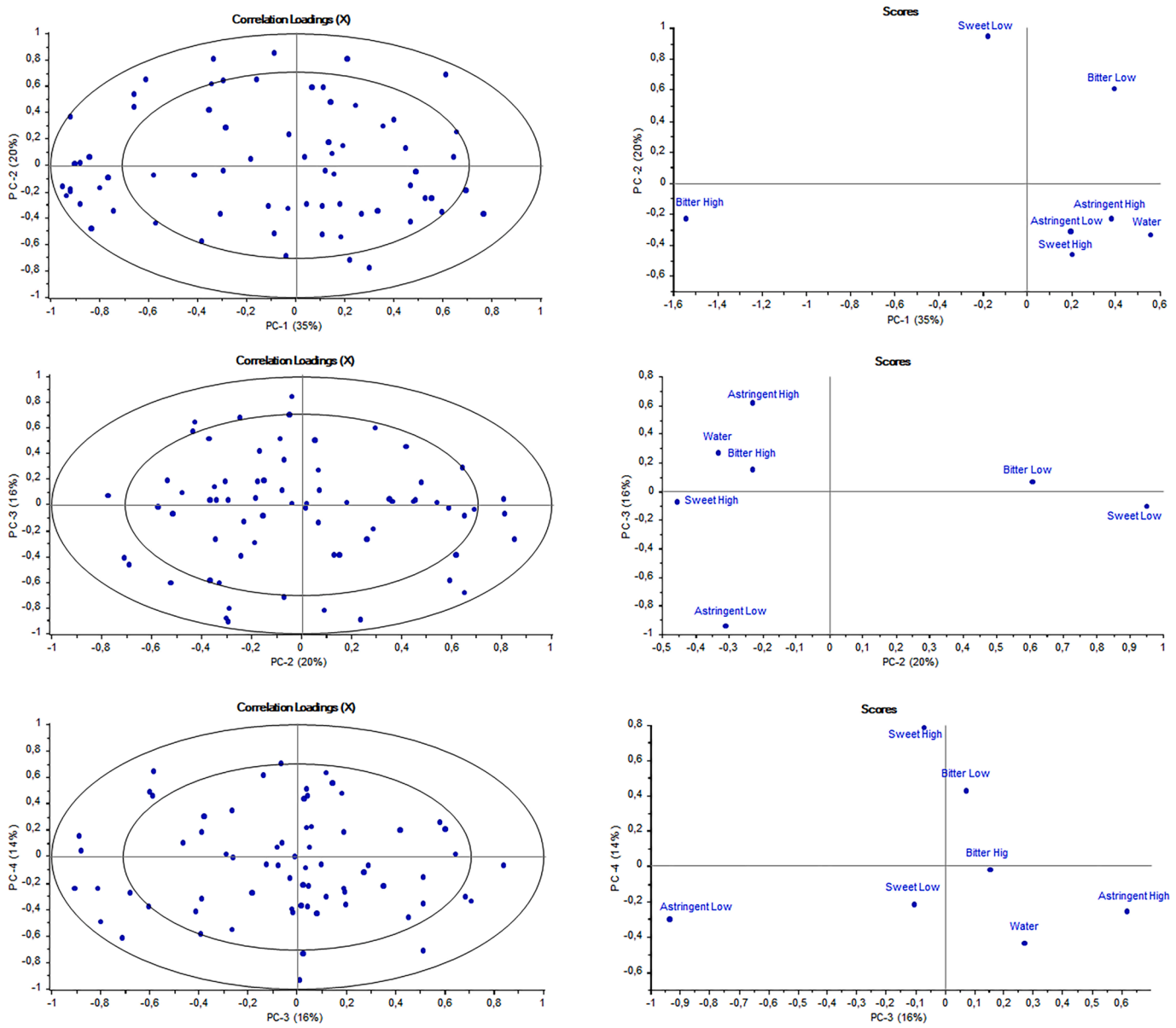


**Fig. 4.**

Fig. 5).

When the effect of cluster membership on SCR was investigated more deeply by including the taste quality and concentration as separate factors in the ANOVA model (thus excluding water), neither main effect of these factors was significant while significant cluster*concentration ($F_{(1,413)} = 9.824$, $p = 0.002$) and cluster*quality ($F_{(2,413)} = 8.892$; $p = 0.0001$) interactions were found. At higher concentrations for all samples, SCR were stronger for *High bitter responders* as compared to *Low bitter responders*, while the opposite was found for lower concentrations, with *Low bitter responders* having higher SCR than *High bitter responders*. For *Low bitter responders,* there was no difference in SCR between high or low concentrations, while for the *High bitter responders,* the higher concentrations elicited enhanced SCR as compared to lower concentrations (Fig. 6a). Furthermore, the *High bitter responders* reported higher SCR to bitterness, and the *Low bitter responders* higher SCR to astringency as compared to bitterness, while no difference between clusters was reported for sweetness (Fig. 6b).

### 3.3. Taste intensity by cluster

Significant effects of sample ($F_{(6,1447)} = 126.08$, $p < 0.0001$), cluster ($F_{(1,1447)} = 10.63$, $p = 0.001$) and replicate ($F_{(2,1447)} = 4.85$, $p = 0.008$) and of the interaction sample*replicate ($F_{(12,1447)} = 1.90$, $p = 0.03$) were found on the intensity ratings. As expected, water was perceived as the least intense sample, followed by astringency, and then by bitter and sweet samples at low concentration and astringency and sweet at high concentration. The high bitter sample was perceived as the most intense. *Low bitter responders* evaluated sample intensities as higher compared to *High bitter responders*, even if the difference between means was small *(Low bitter responders = 19.08; High bitter responders = 16.79)*. Bitter and high astringency samples were perceived as less intense during the third replicate, while no significant change between replicates was found for the other tastes. No significant sample* cluster or replicate*cluster interactions were found.

### 3.4. Implicit affective responses to tastes by cluster

To further examine clusters' responses, correlation between the

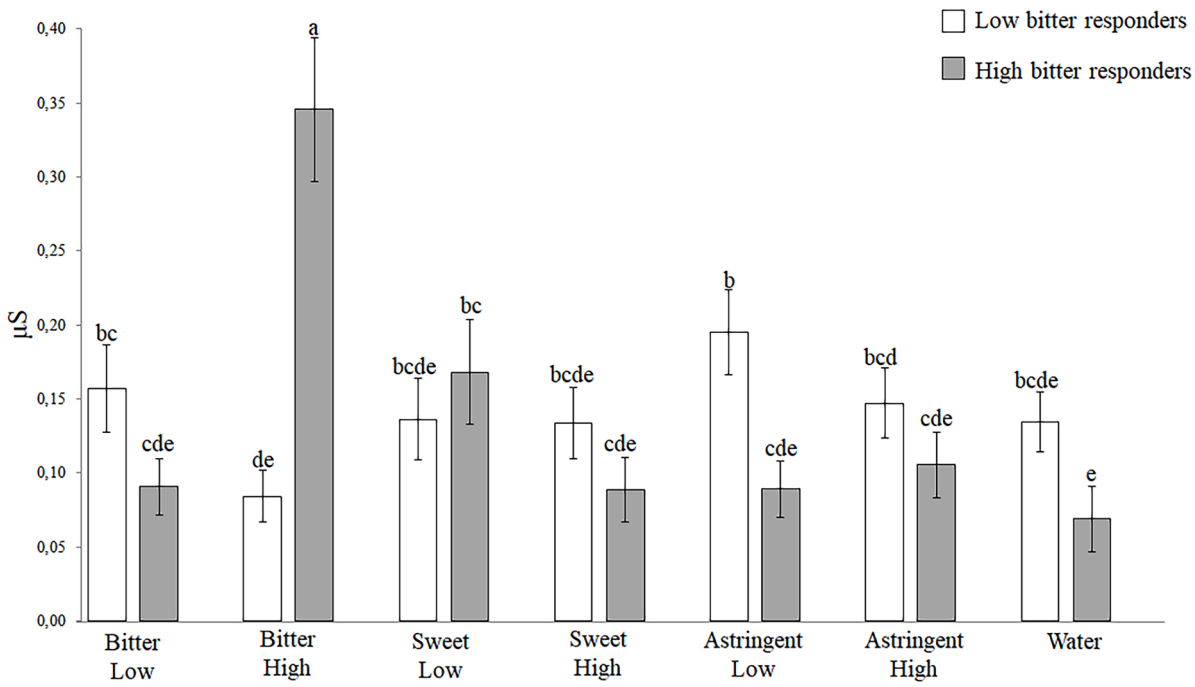


**Fig. 5.**

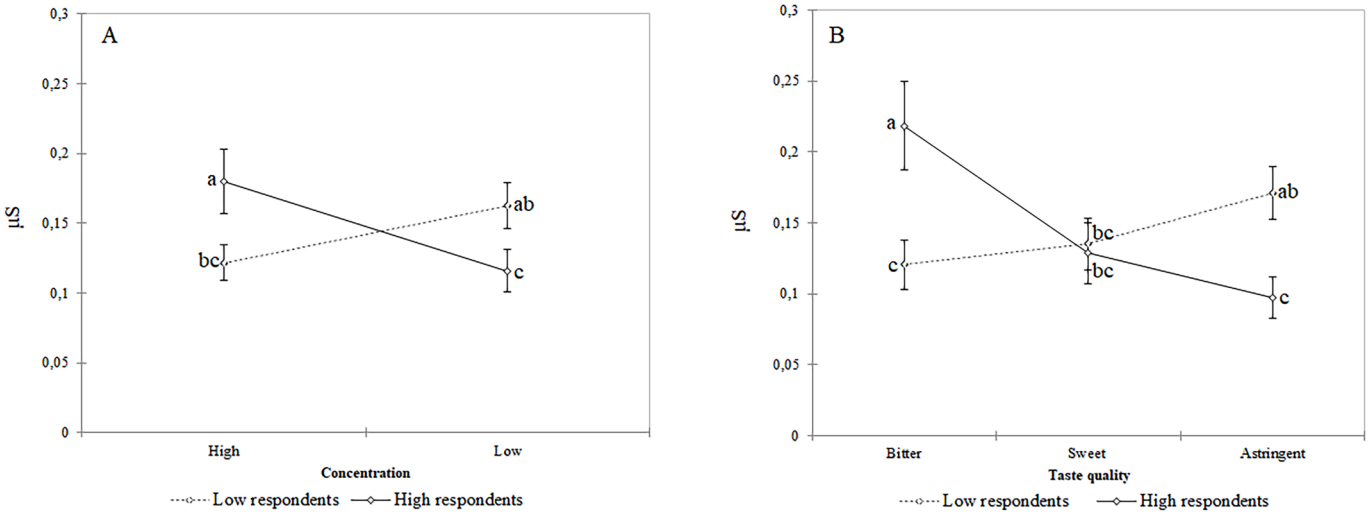


**Fig. 6.**

different variables were examined.

Weak but significant correlations were found in the *High bitter responsive* cluster between SCR, sample intensity and trust ratings. A positive correlation was found between SCR and sample intensity ($r = 0.19$, $p = 0.009$) while a negative one was found between sample intensity and trust ratings ($r = -0.18$, $p = 0.011$). No significant correlations were found in the *Low Bitter responder* cluster.

The two clusters did not differ in trustworthiness ratings in the implicit test ($p = 0.995$), while samples ($F_{(6,1448)} = 1.62$, $p < 0.0001$) and replicates ($F_{(2,1448)} = 10.84$, $p < 0.0001$) were found to differ. No significant interactions for sample*cluster or replicate*cluster were found, while a sample*replicate interaction was found ($F_{(6,1448)} = 5.58$, $p < 0.0001$). The highest trustworthiness scores were observed for sweetness at low concentration, followed by astringency at low and sweet at high concentration. Lower trustworthiness ratings were found for astringency at high concentration, bitter at low concentration and water, while the bitter sample at high concentration elicited the lowest trustworthiness ratings. Trustworthiness for faces was higher in the third as compared to the first and second replicate for strong astringency and weak bitterness and sweetness, while it did not change for the other stimuli indicating that when the taste is not perceived as negative exposure may improve the affective response. No effect of cluster membership, sample quality and concentration, as well as no significant interactions were found for RTs to either trusted and non-trusted faces.

To further examine the effect of trustworthiness on SCR, the yes/no trustworthiness judgment was included in an ANOVA model on SCR as an additional factor together with clusters and samples, but no significant effects were found for yes/no response and its interaction with samples and cluster. All these results taken together indicate that the SCR were not affected by valence, which is reflected in whether individuals trusted or not the faces (Pierguidi et al., 2023).

### 3.5. Cluster characterisation in terms of personality traits

No differences in gender distribution or in age were found between clusters. Subjects in the *High bitter responder* cluster had significantly higher scores in Trait Anxiety and lower scores in Emotional Stability. They also tended to have higher scores for State Anxiety when it was assessed before the skin conductance session ($p = 0.056$) as compared to Low responsive individuals, while no differences between clusters in State anxiety were found when it was assessed before the intensity rating session. No differences between clusters were found for Sensation Seeking and Food Neophobia (Table 1).

## 4. Discussion

As expected, higher SCR to oral stimuli were associated with the higher surprisingness/novelty associated with the first replicate of each stimulus. In contrast, these responses were not, overall, associated with the valence of the sample (i.e., without considering individual differences). These findings expand upon other research that has shown that SCR do not reflect taste valence (Samant & Seo, 2019) but reflect the novelty of tastes (Verastegui-Tena et al., 2018) and other stimuli (Quigley, Lindquist, & Barrett, 2014, Dawson et al 2016).

Based on previous literature on visual stimuli (e.g., Bradley et al., 2001), we expected that SCR would reflect arousal to oral stimuli too. Since strong oral stimuli, particularly if negatively valenced, induce emotional responses that are higher in arousal (e.g., more disgusting, annoying or exciting), we expected that SCR would be associated with the intensity of the stimuli, in particular, for bitter and astringent stimuli. We found that the impact of the oral stimulus intensity on SCR depended on taste quality and individual differences, and were only evident when Ss were classified into high and low bitter responsive clusters. Several sources of arousal may have contributed to this result.

First, it is possible that SCR to oral stimuli reflects firstly novelty/surprisingness (related to the unpredictability of the quality and intensity of taste of the stimuli) and only secondarily the arousal induced by the quality or intensity of the stimuli. In our study, Ss were not aware of the sensory quality of the stimulus being delivered and therefore they could not develop clear expectations of what they would be tasting. Thus, the predominant but constant dimension was the uncertainty related to each stimulus more than the arousal component induced by the taste quality or its intensity. To explore this hypothesis, we recommend further studies informing the subject of their taste quality to avoid the surprise effect.

Secondly, we found relevant individual differences indicating that for some subjects (*High bitter responders*) SCR reflected changes in taste quality and intensity, but this was only partially true for another group of subjects (*Low bitter responders*). The more responsive SCR cluster showed more ANS activation to the most intense stimulus, the bitterness at high intensity, and lower activation to the stimulus with the weakest intensity, water. In contrast, the Low bitter cluster responded more to weak bitterness and astringency than they did to strong bitterness. For this latter cluster, higher intensity tended to induce the lowest SCR. We may hypothesise that, in these latter subjects, SCR reflected more the surprisingness/uncertainty in response to each stimulus (constant for each stimulus) more than arousal induced by the intensity/quality (specific for each stimulus), while in the *High bitter responders* SCR reflected more the arousal component. In fact, the SCR of *Low bitter responders* changed only slightly based on the taste quality and on the intensity and we may hypothesise that for this cluster the surprisingness of the stimuli presentation may have been predominant on other characteristics of the stimuli. For this cluster SCR were also lower than for the other cluster, overall.

Bitterness used as an affective prime stimulus had a negative impact on the perception of trustworthiness in faces, while sweetness had the opposite effect. Additionally, a recent study on a superset of this one (Pierguidi et al., 2023) found that higher intensities of the stimuli resulted in a stronger negative response compared to lower intensities. When experienced at a lower intensity, astringency elicited a positive reaction, but at a higher intensity, it evoked a more negative response. Faster reaction times were observed for stimuli with lower intensity that were perceived positively, but also stronger stimuli evaluated negatively led to quicker reaction times.

Notably, no significant differences were observed in the influence of the priming stimulus on the evaluation of neutral faces between *Low* and *High bitter responders* in the trustworthiness judgment measure, whether measured by trustworthiness score or reaction times, even if a negative correlation between trustworthiness ratings and intensity was observed in *High bitter responders*. These results point out the possibility that SCR reflect (weakly) some component of valence only for some individuals and may also contribute to explain the conflicting results in the literature.

Interestingly, and contrary to our expectations, the *Low bitter responders* rated all the samples as more intense that did the *High bitter responders*. Based on the heightened perceived intensity of the stimuli, it is possible to speculate that individuals in this particular cluster exhibited less uncertainty or ambiguity facilitating the recognition of the tastes in comparison to the other cluster (thus experiencing lower novelty). Their SCR were higher for astringency, which is generally more difficult to recognise than bitterness and sweetness. Furthermore, their SCR did not increase with higher concentrations of the stimulus, which is typically when the sensations become easier to recognize.

Thirdly, it is well established that individuals vary in the extent to which they experience arousal in response to sensory stimuli (Kuppens et al., 2007, 2017; Mehrabian, 1977, 1995). In order to explain the variations in electrodermal responsivity to the chemosensory stimuli used in the present study, various psychological traits were measured. These measures were selected because they tapped into underlying responses to arousing stimuli which, in turn, are reflected in higher reactivity (Bradley et al., 2001). In the present study, the *High bitter responders* were more anxious and neurotic (the reverse trait of the emotional stability) than the other cluster, in line with our expectations and findings of a positive relationship between neuroticism and electrodermal responsivity (Brumbaugh et al., 2013; Norris et al., 2007). As was evident here for the SCR to intense bitterness, it has also been noted that those high in neuroticism show especially high responses to highly unpleasant and/or aversive stimuli that can be indicative of a threat (Rosebrock et al., 2017). This is consistent with the interpretations of

**Table 1**
Cluster characteristics. Significant differences are in bold. Different letters indicate a significant difference ($p < 0.05$).

| Variables | Cluster 1 (Low bitter respondents) | Cluster 2 (High bitter respondents) | Chi-Square/F value | *p*-Value |
|---|---|---|---|---|
| Gender | | | | |
| Women | 61.9% | 55.6% | 0.275 | 0.6 |
| Men | 38.1% | 44.4% | | |
| Age | 27.43 | 28.67 | 0.57 | 0.453 |
| Personality traits | | | | |
| Trait Anxiety (STAI-Y) | **39.83[b]** | **46.12[a]** | **7.408** | **0.008** |
| State Anxiety before implicit task (STAI-Y) | 31.46 | 35.19 | **3.789** | **0.056** |
| State Anxiety before intensity rating (STAI-Y) | 32.57 | 32.52 | 0.001 | 0.977 |
| Sensation Seeking Scale (SSS) | 101.38 | 100.67 | 0.031 | 0.861 |
| Food Neophobia Scale (FN) | 27.12 | 25.32 | 0.304 | 0.745 |
| Emotional stability (BFQ-2 subscale) | **66.48[a]** | **60.62[b]** | **3.993** | **0.05** |

high levels of bitterness being a 'warning' stimulus (Laureati et al., 2018).

In contrast, also evident in the current data, those low in neuroticism show comparable levels of reactivity to both arousing and non-arousing stimuli (Norris et al., 2007). Those low in extraversion (that is, introverts) have high levels of anxiety and seek to control their arousal levels via behaviours aimed at reducing external stimulation (Corr, 2004). Although, the trait of extraversion was not measured in this study, the higher state and trait anxiety shown by the *High bitter responder* group are consistent with introversion. Furthermore, it has been pointed out that the electrodermal activity is influenced primarily by the activation of neurophysiological behavioural inhibition system, that is an anxiety system involved in response to punishment, to passive avoidance, or to frustrative non-reward (Dawson et al., 2016; Fowles, 1988), and a positive relationship between anxiety and electrodermal responses has been widely reported (Krusemark & Li, 2012). The present results are therefore consistent with the major personality theories (Corr, 2004; Eysenck, 1967; Gray, 1970) that characterise the main dimensions of personality in terms of variations in reactivity to sensory stimuli as a function of their degree of reward or aversiveness.

Finally, it should also be considered that the study was limited to PROP medium tasters with the aim of studying the effect of personality traits eliminating the confounding factor of taste sensitivity. Since variability in PROP responding has also been linked to responses to other taste and oral stimuli, reduced responsiveness to oral sensations may have contributed to the limited variability in skin conductance responses. Previous findings in fact suggested a link between PROP taste perception and biologically relevant patterns of emotional responding, with facilitated response priming to emotional stimuli that emerged in PROP supertasters but not in PROP-insensitive subjects immediately after emotional stimulus exposure (Herbert et al., 2014). However, interestingly, we did report large individual differences in SCR to bitterness elicited by caffeine in PROP medium tasters, associated with personality traits. This further reinforces the hypothesis of a modulation of the affective and sensory response by personality traits (Spinelli et al., 2018).

## 5. Conclusions

These findings build and expand upon other research that has shown that SCR reflect a variety of dimensions (Quigley, Lindquist, & Barrett, 2014; Dawson et al., 2016) and suggest caution in interpreting SCR to oral stimuli. Taken together, these results provide evidence that SCR to taste stimuli are not primarily indicative of valence but are instead mainly driven by different sources of arousal related to the unpredictability (novelty), intensity and quality of the stimuli. Importantly, these effects were found to vary significantly at an individual level, leading to substantial differences in SCR among participants.

Of particular interest is the partial confirmation of our hypothesis regarding the relationship between SCR and stimulus intensity. While it held true for a subgroup of subjects who exhibited remarkably high SCR in response to the high bitter sample, SCR was largely unrelated to intensity for another group of subjects differing in personality. This intriguing finding suggests that the arousing effects of oral stimuli are not universally shared and that the complex interplay between intensity, arousal, and valence in the context of oral stimuli requires further investigation.

This suggests that SC can contribute to a better understanding of the individual differences in taste and oral experience, but also the studies on SCR to oral stimuli may further expand knowledge on SC, pointing out a link between taste responsiveness and the sympathetic nervous system activity. These results highlight the need for a deeper understanding of the individual variability and underlying mechanisms that modulate physiological and sensory responses to taste stimuli. By unravelling the intricate relationship between personality, intensity (taste responsiveness), arousal, and valence in oral stimuli, future research can shed light on the unique physiological profiles of individuals and their responses to taste stimuli.

## CRediT authorship contribution statement

**S. Spinelli:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Supervision, Project administration, Funding acquisition. **L. Pierguidi:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization. **G. Gavazzi:** Software, Data curation, Formal analysis. **C. Dinnella:** Methodology, Writing – review & editing. **A. De Toffoli:** Conceptualization, Investigation, Data curation. **J. Prescott:** Conceptualization, Methodology, Writing – original draft. **E. Monteleone:** Conceptualization, Methodology, Writing – review & editing, Supervision.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sara Spinelli reports financial support was provided by Fondazione CR Firenze. JP Editor EM Editor SS, CD member of the editorial board of FQAP.

## Data availability

Data will be made available on request.

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## References

Aluja, A., Kuhlman, M., & Zuckerman, M. (2010). Development of the Zuckerman–Kuhlman–Aluja personality questionnaire (ZKA–PQ): A factor/facet version of the Zuckerman-Kuhlman personality questionnaire (ZKPQ). *Journal of Personality Assessment, 92*(5), 416–431.

Bagozzi, R. P., & Yi, Y. (1988). On the evaluation of structural equation models. *Journal of the Academy of Marketing Science, 16*(1), 74–94. https://doi.org/10.1007/BF02723327

Bajec, M. R., & Pickering, G. J. (2008). Astringency: Mechanisms and perception. *Critical Reviews in Food Science and Nutrition, 48*(9), 858–875.

Barrett, L. F., & Westlin, C. (2021). Navigating the science of emotion. In *Emotion Measurement* (pp. 39–84). Elsevier. https://doi.org/10.1016/B978-0-12-821124-3.00002-8.

Bartoshuk, L. M., Duffy, V. B., Green, B. G., Hoffman, H. J., Ko, C.-W., Lucchina, L. A., Marks, L. E., Snyder, D. J., & Weiffenbach, J. M. (2004). Valid across-group comparisons with labeled scales: The gLMS versus magnitude matching. *Physiology & Behavior, 82*(1), 109–114.

Bensafi, M., Rouby, C., Farget, V., Bertrand, B., Vigoroux, M., & Holley, A. (2002). Autonomic nervous system responses to odours: The role of pleasantness and arousal. *Chemical Senses, 27*(8), 703–709. https://doi.org/10.1093/chemse/27.8.703

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion, 1*(3), 276–298. https://doi.org/10.1037/1528-3542.1.3.276

Bradley, M. M., & Lang, P. J. (2000). Measuring emotion: Behavior, feeling, and physiology. In R. D. L. Lane, L. Nadel, G. L. Ahern, J. Allen, & A. W. Kaszniak (Eds.), *Cognitive Neuroscience of Emotion* (pp. 25–49). Oxford University Press.

Brumbaugh, C. C., Kothuri, R., Marci, C., Siefert, C., & Pfaff, D. D. (2013). Physiological Correlates of the Big 5: Autonomic Responses to Video Presentations. *Applied Psychophysiology and Biofeedback, 38*(4), 293–301. https://doi.org/10.1007/s10484-013-9234-5

Cacioppo, J., Berntson, G., Larsen, J., Poehlmann, K., & Ito, T. (2000). The psychophysiology of emotion. In R. Lewis, & J. Haviland-Jones (Eds.), *The Handbook of Emotion* (pp. 173–191). Guilford Press.
Caprara, G. V., Barbaranelli, C., Borgogni, L., & Vecchione, M. (2007). *BFQ-2: Manuale.* Florence, Italy: Giunti OS.
Cardello, A. V., & Jaeger, S. R. (2021). Questionnaires should be the default method in food-related emotion research. *Food Quality and Preference, 92*, Article 104180. https://doi.org/10.1016/j.foodqual.2021.104180
Corr, P. J. (2004). Reinforcement sensitivity theory and personality. *Neuroscience & Biobehavioral Reviews, 28*(3), 317–332. https://doi.org/10.1016/j.neubiorev.2004.01.005
Danner, L., Sidorkina, L., Joechl, M., & Duerrschmid, K. (2014). Make a face! Implicit and explicit measurement of facial expressions elicited by orange juices using face reading technology. *Food Quality and Preference, 32*, 167–172. https://doi.org/10.1016/j.foodqual.2013.01.004
Dawson, M. E., Schell, A. M., & Filion, D. L. (2016). The Electrodermal System. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of Psychophysiology* (4th ed., pp. 217–243). Cambridge University Press. https://doi.org/10.1017/9781107415782.010.
de Wijk, R. A., & Boesveldt, S. (2016). Responses of the Autonomic Nervous System to Flavors. In B. Piqueras-Fiszman, & C. Spence (Eds.), *Multisensory Flavor Perception: From Fundamental Neuroscience Through to the Marketplace* (pp. 249–268). Elsevier. https://doi.org/10.1016/B978-0-08-100350-3.00013-4.
de Wijk, R. A., Kooijman, V., Verhoeven, R. H. G., Holthuysen, N. T. E., & de Graaf, C. (2012). Autonomic nervous system responses on and facial expressions to the sight, smell, and taste of liked and disliked foods. *Food Quality and Preference, 26*(2), 196–203. https://doi.org/10.1016/j.foodqual.2012.04.015
Dinnella, C., Monteleone, E., Piochi, M., Spinelli, S., Prescott, J., Pierguidi, L., Gasperi, F., Laureati, M., Pagliarini, E., & Predieri, S. (2018). Individual variation in PROP status, fungiform papillae density, and responsiveness to taste stimuli in a large population sample. *Chemical Senses, 43*(9), 697–710.
Dinnella, C., Recchia, A., Fia, G., Bertuccioli, M., & Monteleone, E. (2009). saliva characteristics and individual sensitivity to phenolic astringent stimuli. *Chemical Senses, 34*(4), 295–304. https://doi.org/10.1093/chemse/bjp003
Dinnella, C., Recchia, A., Vincenzi, S., Tuorila, H., & Monteleone, E. (2010). Temporary modification of salivary protein profile and individual responses to repeated phenolic astringent stimuli. *Chemical Senses, 35*(1), 75–85. https://doi.org/10.1093/chemse/bjp084
Dotsch, R., & Todorov, A. (2012). Reverse correlating social face perception. *Social Psychological and Personality Science, 3*(5), 562–571. https://doi.org/10.1177/1948550611430272
Drewnowski, A., Henderson, S. A., & Barratt-Fornell, A. (1998). Genetic sensitivity to 6-n-propylthiouracil and sensory responses to sugar and fat mixtures. *Physiology & Behavior, 63*(5), 771–777.
Eysenck, H. J. (1967). Personality and extra-sensory perception. *Journal of the Society for Psychical Research*.
Feeney, E. L., & Hayes, J. E. (2014). Regional differences in suprathreshold intensity for bitter and umami stimuli. *Chemosensory Perception, 7*(3–4), 147–157. https://doi.org/10.1007/s12078-014-9166-3
Flykt, A., Esteves, F., & Öhman, A. (2007). Skin conductance responses to masked conditioned stimuli: Phylogenetic/ontogenetic factors versus direction of threat? *Biological Psychology, 74*(3), 328–336. https://doi.org/10.1016/j.biopsycho.2006.08.004
Fowles, D. C. (1988). Psychophysiology and psychopathology: A motivational approach. *Psychophysiology, 25*(4), 373–391. https://doi.org/10.1111/j.1469-8986.1988.tb01873.x
Galloway, A. T., Lee, Y., & Birch, L. L. (2003). Predictors and consequences of food neophobia and pickiness in young girls. *Journal of the American Dietetic Association, 103*(6), 692–698. https://doi.org/10.1053/jada.2003.50134
Gent, J. F., & Bartoshuk, L. M. (1983). Sweetness of sucrose, neohesperidin dihydrochalcone, and saccharin is related to genetic ability to taste the bitter substance 6-n-propylthiouracil. *Chemical Senses, 7*(3–4), 265–272.
Gray, J. A. (1970). The psychophysiological basis of introversion-extraversion. *Behaviour Research and Therapy, 8*(3), 249–266. https://doi.org/10.1016/0005-7967(70)90069-0
Hayes, J. E., Bartoshuk, L. M., Kidd, J. R., & Duffy, V. B. (2008). Supertasting and PROP bitterness depends on more than the TAS2R38 gene. *Chemical Senses, 33*(3), 255–265.
Hayes, J. E., & Keast, R. S. J. (2011). Two decades of supertasting: Where do we stand? *Physiology & Behavior, 104*(5), 1072–1074. https://doi.org/10.1016/j.physbeh.2011.08.003
Hayes, J. E., Sullivan, B. S., & Duffy, V. B. (2010). Explaining variability in sodium intake through oral sensory phenotype, salt sensation and liking. *Physiology & Behavior, 100*(4), 369–380.
Herbert, C., Platte, P., Wiemer, J., Macht, M., & Blumenthal, T. D. (2014). Supertaster, super reactive: Oral sensitivity for bitter taste modulates emotional approach and avoidance behavior in the affective startle paradigm. *Physiology & Behavior, 135*, 198–207. https://doi.org/10.1016/j.physbeh.2014.06.002
Hoogeveen, H. R., Jolij, J., ter Horst, G. J., & Lorist, M. M. (2016). Brain potentials highlight stronger implicit food memory for taste than health and context associations. *PLOS ONE, 11*(5), e0154128.
Iatridi, V., Hayes, J. E., & Yeomans, M. R. (2019). Reconsidering the classification of sweet taste liker phenotypes: A methodological review. *Food Quality and Preference, 72*, 56–76. https://doi.org/10.1016/j.foodqual.2018.09.001
Jaeger, S. R., Chheang, S. L., & Prescott, J. (2021). Variations in the strength of association between food neophobia and food and beverage acceptability: A data-driven exploratory study of an arousal hypothesis. *Nutrients, 13*(10), 3657. https://doi.org/10.3390/nu13103657
Jaeger, S. R., Hedderley, D., & Prescott, J. (2023). High arousal as the source of food rejection in food neophobia. *Food Research International.* in press.
Katkin, E. S. (1975). Electrodermal lability: A psychophysiological analysis of individual differences in response to stress. *Stress and Anxiety, 2*, 141–176.
Kim, J.-Y., Prescott, J., & Kim, K.-O. (2014). Patterns of sweet liking in sucrose solutions and beverages. *Food Quality and Preference, 36*, 96–103. https://doi.org/10.1016/j.foodqual.2014.03.009
Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology, 84*(3), 394–421. https://doi.org/10.1016/j.biopsycho.2010.03.010
Krusemark, E. A., & Li, W. (2012). Enhanced olfactory sensory perception of threat in anxiety: An event-related fMRI study. *Chemosensory Perception, 5*(1), 37–45. https://doi.org/10.1007/s12078-011-9111-7
Kuppens, P., Tuerlinckx, F., Yik, M., Koval, P., Coosemans, J., Zeng, K. J., & Russell, J. A. (2017). The relation between valence and arousal in subjective experience varies with personality and culture: relation of valence to arousal. *Journal of Personality, 85*(4), 530–542. https://doi.org/10.1111/jopy.12258
Kuppens, P., Van Mechelen, I., Nezlek, J. B., Dossche, D., & Timmermans, T. (2007). Individual differences in core affect variability and their relationship to personality and psychological adjustment. *Emotion, 7*(2), 262–274. https://doi.org/10.1037/1528-3542.7.2.262
Lagast, S., De Steur, H., Gadeyne, S., Hödl, S., Staljanssens, W., Vonck, K., Boon, P., Gellynck, X., & De Herdt, V. (2020). Heart rate, electrodermal responses and frontal alpha asymmetry to accepted and non-accepted solutions and drinks. *Food Quality and Preference, 82*, Article 103893. https://doi.org/10.1016/j.foodqual.2020.103893
Lang, P. J., Greenwald, M. K., BradleyY, M. M., & Hamm, A. O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology, 30*(3), 261–273. https://doi.org/10.1111/J.1469-8986.1993.TB03352.X
Laureati, M., Spinelli, S., Monteleone, E., Dinnella, C., Prescott, J., Cattaneo, C., Proserpio, C., De Toffoli, A., Gasperi, F., Endrizzi, I., Torri, L., Peparaio, M., Arena, E., Bonello, F., Condelli, N., Di Monaco, R., Gatti, E., Piasentier, E., Tesini, F., & Pagliarini, E. (2018). Associations between food neophobia and responsiveness to "warning" chemosensory sensations in food products in a large population sample. *Food Quality and Preference, 68*, 113–124. https://doi.org/10.1016/j.foodqual.2018.02.007
Leterme, A., Brun, L., Dittmar, A., & Robin, O. (2008). Autonomic nervous system responses to sweet taste: Evidence for habituation rather than pleasure. *Physiology and Behavior, 93*(4–5), 994–999. https://doi.org/10.1016/j.physbeh.2008.01.005
Lim, J., & Green, B. G. (2007). The psychophysical relationship between bitter taste and burning sensation: Evidence of qualitative similarity. *Chemical Senses, 32*(1), 31–39. https://doi.org/10.1093/chemse/bjl033
Ly, A. (2001). PROP (6-n-Propylthiouracil) tasting and sensory responses to caffeine, sucrose, neohesperidin dihydrochalcone and chocolate. *Chemical Senses, 26*(1), 41–47. https://doi.org/10.1093/chemse/26.1.41
Masi, C., Dinnella, C., Monteleone, E., & Prescott, J. (2015). The impact of individual variations in taste sensitivity on coffee perceptions and preferences. *Physiology & Behavior, 138*, 219–226. https://doi.org/10.1016/j.physbeh.2014.10.031
Mendes, W. B. (2016). Emotion and the Autonomic Nervous System. In L. E. Barrett, M. Lewis, & J. Haviland-Jones (Eds.), *Handbook of Emotions* (4th ed., pp. 166–181). New York: NY: Guilford Publications Inc.
Mehrabian, A. (1977). Individual differences in stimulus screening and arousability. *Journal of personality, 45*(2), 237–250.
Mehrabian, A. (1995). Theory and evidence bearing on a Scale of Trait Arousability. *Current Psychology, 14*(1), 3–28. https://doi.org/10.1007/BF02686870
Mohamad, M. M., Sulaiman, N. L., Sern, L. C., & Salleh, K. M. (2015). Measuring the validity and reliability of research instruments. *Procedia – Social and Behavioral Sciences, 204*, 164–171. https://doi.org/10.1016/j.sbspro.2015.08.129
Monteleone, E., Frewer, L., Wakeling, l., & Mela, D. J. (1998). Individual differences in starchy food consumption: The application of preference mapping. *Food Quality and Preference, 9*(4), 211–219. https://doi.org/10.1016/S0950-3293(97)00070-0
Monteleone, E., Spinelli, S., Dinnella, C., Endrizzi, I., Laureati, M., Pagliarini, E., … Tesini, F. (2017). Exploring influences on food choice in a large population sample: The Italian Taste project. *Food Quality and Preference, 59*, 123–140. https://doi.org/10.1016/j.foodqual.2017.02.013
Nolden, A. A., McGeary, J. E., & Hayes, J. E. (2020). Predominant qualities evoked by quinine, sucrose, and capsaicin associate with PROP bitterness, but not *TAS2R38* genotype. *Chemical Senses, 45*(5), 383–390. https://doi.org/10.1093/chemse/bjaa028
Norris, C. J., Larsen, J. T., & Cacioppo, J. T. (2007). Neuroticism is associated with larger and more prolonged electrodermal responses to emotionally evocative pictures. *Psychophysiology, 44*(5), 823–826. https://doi.org/10.1111/j.1469-8986.2007.00551.x
Nunnally, J. C. (1978). *Psychomettic theory McGraw Hill Book Company.* INC New York.
Pangborn, R. M. (1970). Individual variation in affective responses to taste stimuli. *Psychonomic Science, 21*(2), 125–126. https://doi.org/10.3758/BF03335798
Pedrabissi, L., & Santinello, M. (1989). Verifica della validità dello STAI forma Y di Spielberger. [Verification of the validity of the STAI, Form Y, by Spielberger.]. *Giunti Organizzazioni Speciali, 191–192*, 11–14.
Pickering, G. J., & Robert, G. (2006). Perception of mouthfeel sensations elicited by red wine are associated with sensitivity to 6-n-propylthiouracil. *Journal of Sensory Studies, 21*(3), 249–265.
Pierguidi, L., Prescott, J., Spinelli, S., Dinnella, C., De Toffoli, A., White, T. L., & Monteleone, E. (2023). Chemosensory quality and intensity reflected in implicit

affective responses. *Food Quality and Preference, 108*, Article 104857. https://doi.org/10.1016/j.foodqual.2023.104857

Piochi, M., Dinnella, C., Spinelli, S., Monteleone, E., & Torri, L. (2021). Individual differences in responsiveness to oral sensations and odours with chemesthetic activity: Relationships between sensory modalities and impact on the hedonic response. *Food Quality and Preference, 88*, Article 104112. https://doi.org/10.1016/j.foodqual.2020.104112

Pliner, P., & Hobden, K. (1992). Development of a scale to measure the trait of food neophobia in humans. *Appetite, 19*(2), 105–120.

Prescott, J., Chheang, S. L., & Jaeger, S. R. (2022). Food neophobia: Higher responsiveness to sensory properties but low engagement with foods generally. *Journal of Sensory Studies, 37*(5). https://doi.org/10.1111/joss.12771

Prescott, J., Ripandelli, N., & Wakeling, I. (2001). Binary taste mixture interactions in prop non-tasters, medium-tasters and super-tasters. *Chemical Senses, 26*(8), 993–1003.

Quigley, K. S., Lindquist, K. A., & Barrett, L. F. (2014). Inducing and measuring emotion and affect: Tips, tricks, and secrets. In H. T. Reis, & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 220–250). New York, NY: Cambridge University Press.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114*(3), 510.

Rosebrock, L. E., Hoxha, D., Norris, C., Cacioppo, J. T., & Gollan, J. K. (2017). Skin conductance and subjective arousal in anxiety, depression, and comorbidity: Implications for affective reactivity. *Journal of Psychophysiology, 31*(4), 145–157. https://doi.org/10.1027/0269-8803/a000176

Rossier, J., Aluja, A., Blanch, A., Barry, O., Hansenne, M., Carvalho, A. F., Valdivia, M., Wang, W., Desrichard, O., & Hyphantis, T. (2016). Cross-cultural generalizability of the alternative five-factor model using the zuckerman–kuhlman–aluja personality questionnaire. *European Journal of Personality, 30*(2), 139–157.

Rousmans, S. (2000). Autonomic nervous system responses associated with primary tastes. *Chemical Senses, 25*(6), 709–718. https://doi.org/10.1093/chemse/25.6.709

Samant, S. S., Chapko, M. J., & Seo, H.-S. (2017). Predicting consumer liking and preference based on emotional responses and sensory perception: A study with basic taste solutions. *Food Research International, 100*, 325–334. https://doi.org/10.1016/j.foodres.2017.07.021

Samant, S. S., & Seo, H. (2019). Personality traits affect the influences of intensity perception and emotional responses on hedonic rating and preference rank toward basic taste solutions. *Journal of Neuroscience Research, 97*(3), 276–291. https://doi.org/10.1002/jnr.24321

Samant, S. S., & Seo, H.-S. (2018). Personality traits affect the influences of intensity perception and emotional responses on hedonic rating and preference rank toward basic taste solutions. *Journal of Neuroscience Research*. https://doi.org/10.1002/jnr.24321

Schouteten, J. J. (2021). Are questionnaires the best way to measure emotions for food products and beverages? *Food Quality and Preference, 92*, Article 104122. https://doi.org/10.1016/j.foodqual.2020.104122

Shiota, M. N., Neufeld, S. L., Yeung, W. H., Moser, S. E., & Perea, E. F. (2011). Feeling good: Autonomic nervous system responding in five positive emotions. *Emotion, 11*(6), 1368–1378. https://doi.org/10.1037/a0024278

Siddle, D. A. T. (1991). Orienting, habituation, and resource allocation: An associative analysis. *Psychophysiology, 28*(3), 245–259. https://doi.org/10.1111/j.1469-8986.1991.tb02190.x

Smith, B. D., Perlstein, W. M., Davidson, R. A., & Michael, K. (1986). Sensation seeking: Differential effects of relevant, novel stimulation on electrodermal activity. *Personality and Individual Differences, 7*(4), 445–452. https://doi.org/10.1016/0191-8869(86)90122-4

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait Anxiety Inventory STAI (form Y)('self-evaluation questionnaire')*. Palo Alto, CA: Consulting Psychologists Press.

Spinelli, S., Prescott, J., Pierguidi, L., Dinnella, C., Arena, E., Braghieri, A., … Monteleone, E. (2021). Phenol-rich food acceptability: The influence of variations in sweetness optima and sensory-liking patterns. *Nutrients, 13*(3), 866.

Spinelli, S., De Toffoli, A., Dinnella, C., Laureati, M., Pagliarini, E., Bendini, A., Braghieri, A., Gallina Toschi, T., Sinesio, F., Torri, L., Gasperi, F., Endrizzi, I., Magli, M., Borgogno, M., di Salvo, R., Favotto, S., Prescott, J., & Monteleone, E. (2018). Personality traits and gender influence liking and choice of food pungency. *Food Quality and Preference, 66*, 113–126. https://doi.org/10.1016/j.foodqual.2018.01.014

Tepper, B. J., Melis, M., Koelliker, Y., Gasparini, P., Ahijevych, K. L., & Tomassini Barbarossa, I. (2017). Factors influencing the phenotypic characterization of the oral marker, PROP. *Nutrients, 9*(12), 1275.

Todorov, A., Dotsch, R., Porter, J. M., Oosterhof, N. N., & Falvello, V. B. (2013). Validation of data-driven computational models of social perception of faces. *Emotion, 13*(4), 724–738. https://doi.org/10.1037/a0032335

Treinen, E., Corneille, O., & Luypaert, G. (2012). L-eye to me: The combined role of Need for Cognition and facial trustworthiness in mimetic desires. *Cognition, 122*(2), 247–251. https://doi.org/10.1016/j.cognition.2011.10.006

Verastegui-Tena, L., van Trijp, H., & Piqueras-Fiszman, B. (2018). Heart rate and skin conductance responses to taste, taste novelty, and the (dis)confirmation of expectations. *Food Quality and Preference, 65*, 1–9. https://doi.org/10.1016/j.foodqual.2017.12.012

Wajrock, S., Antille, N., Rytz, A., Pineau, N., & Hager, C. (2008). Partitioning methods outperform hierarchical methods for clustering consumers in preference mapping. *Food Quality and Preference, 19*(7), 662–669. https://doi.org/10.1016/j.foodqual.2008.06.002

Ward, J. H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association, 58*(301), 236–244. https://doi.org/10.1080/01621459.1963.10500845

Wilson-Mendenhall, C. D., Barrett, L. F., Simmons, W. K., & Barsalou, L. W. (2011). Grounding emotion in situated conceptualization. *Neuropsychologia, 49*(5), 1105–1127. https://doi.org/10.1016/j.neuropsychologia.2010.12.032

Yeomans, M. R., Tepper, B. J., Rietzschel, J., & Prescott, J. (2007). Human hedonic responses to sweetness: Role of taste genetics and anatomy. *Physiology & Behavior, 91*(2–3), 264–273. https://doi.org/10.1016/j.physbeh.2007.03.011

Yoshino, A., Kimura, Y., Yoshida, T., Takahashi, Y., & Nomura, S. (2005). Relationships between temperament dimensions in personality and unconscious emotional responses. *Biological Psychiatry, 57*(1), 1–6. https://doi.org/10.1016/j.biopsych.2004.09.027

Zuckerman, M. (1971). Dimensions of sensation seeking. *Journal of Consulting and Clinical Psychology, 36*(1), 45.