Odour-modulation of taste ratings by chefs

Robert A. Boakes a,*, Helga Hemberger b

a School of Psychology, University of Sydney, Australia
b National Hospital for Neurology and Neurosurgery, London, UK

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ABSTRACT

Odour-modulation of taste perception refers to the finding that adding a tasteless odorant can change a taste's attributes. An extensively studied example is sweetness enhancement, whereby adding an odorant such as caramel makes a sucrose solution taste sweeter. Experiment 1 tested whether chefs would display odour-modulation to the same extent as controls. When asked to rate sucrose and citric acid solutions that contained an odorant, caramel, cedryl, or no odorant, participants showed sweetness enhancement and sourness suppression by caramel. Cedral produced sourness enhancement of sucrose – a new finding – but, paradoxically, when added to citric acid it decreased sourness ratings and increased sweetness ratings. The only difference detected between chefs and controls was in the way that citral affected sourness ratings of sucrose solutions. Experiment 2 tested participants without professional culinary experience on their food/drink associations to caramel and cedryl. The results showed that, while the associations evoked by caramel were almost always sweet foods or drinks, associations to cedryl varied widely in terms of sweetness and sourness. The latter suggests an explanation for the mixed pattern of results obtained for citral in Experiment 1.

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0. Introduction

Perception of the ‘taste’ or ‘flavour’ of a food or drink depends on several different sensory inputs. The present research focused on the way that stimulation of olfactory receptors in the nasal cavity combines with stimulation of the taste receptors on the tongue and in the mouth to produce perception of the ‘taste’ of what is in the mouth. As discussed in recent reviews (e.g. Auvey & Spence, 2008; Stevenson, 2009), several kinds of odour-induced taste modulation have been investigated. The most extensively studied has been termed ‘sweetness enhancement’, the increase in sweetness of a sucrose solution that is produced by adding an odorant with no taste property whatsoever (Bingham, Birch, de Graaf, Behan, & Perring, 1990; Clark & Lawless, 1994; Frank & Byram, 1988; Schifferstein & Verlegh, 1996; Stevenson, Prescott, & Boakes, 1999). For example, adding a strawberry flavorant that produces a retronasal odor enhances the sweetness of sucrose solutions across a range of concentrations, but pinching the nose while the judgement is made abolishes this sweetness enhancement effect (Frank & Byram, 1988; Frank, Ducheny, & Mize, 1989). This indicates that the effects are psychological in nature, not chemical (Prescott, 1999). In addition to these examples based on artificial solutions, the effect has also been demonstrated in a familiar beverage; the addition of a ‘dark chocolate’ odorant was found to increase the perceived bitterness of a cocoa drink (Labbe, Damevin, Vaccher, Morgenegg, & Martin, 2006).

Additional types of odour-induced taste modulation were also examined in the present experiment. One was sourness suppression, whereby adding a sweet odor can decrease the perceived sourness of a sour-tasting solution. Thus, caramel has been found to suppress the sourness of citric acid (Stevenson et al., 1999). Another type was sweetness suppression, whereby an odor can suppress the sweetness of a sweet-tasting solution, as reported by Stevenson et al. (1999), who found that the odorants, angelica oil and cedryl acetate, both reduced the sweetness of sucrose. To date, however, there has been no evidence for a fourth potential effect examined in the present study, sourness enhancement, whereby an odorant can enhance the sourness of a sour taste.

The effect of an odorant on taste perception can to some extent be predicted from the sensory character of the odor it produces. For example, the degree to which an odor is judged as ‘sweet’ when sniffed predicts the degree to which it increases the sweetness of the solution to which it is added. Thus, in an experiment employing a variety of odours it was found that the sweetest smelling odorant, caramel, enhanced the sweetness of sucrose and suppressed the sourness of citric acid; in contrast odorants that were the least “sweet” smelling suppressed the sweetness of sucrose (Stevenson et al., 1999).
As is common in such research, the participants in the above studies were university students without any explicit training related to taste or odour perception. Training and experience can enhance perceptual abilities in various domains. With regard to odours and flavours, Rabin (1988) showed that familiarity with target and contaminant odours, acquired over a lifetime, increased the likelihood that participants would be able to discriminate simultaneously presented odours and detect contamination by another odour. He noted that these findings are consistent with the ability of perfumers and odour experts to treat odour mixtures analytically, whereas the lay person may be unable to determine the components of an odour mixture (Rabin, 1988). Untutored experience with wine can improve performance in a short-term wine recognition task (Hughson & Boakes, 2009), while extensive training is generally found to improve discrimination, recognition and identification of wines; wine experts are notably far better than novices at detecting component tastes and odours in wines (e.g. Ballester, Patris, Symoneaux, & Valentin, 2008; Hughson & Boakes, 2001). Various studies have suggested that the skills displayed by wine experts depend largely on cognitive processes, including knowledge of wine varieties and their typical characteristics (e.g. Hughson & Boakes, 2002), and that their basic sensory abilities are no different from those of novices (e.g. Bende & Nordin, 1997).

A number of studies have investigated whether analytic training or instructions might reduce the extent to which odours modulate taste perception. These have at best found a limited impact of such manipulations. However, all have used non-expert subjects as participants (e.g. Prescott, 1999; Prescott, Johnston, & Francis, 2004; Stevenson, 2001). The question therefore arises as to whether odour modulation of tastes would occur to a smaller extent in professionals such as chefs, since during training they gain extensive practice in discriminating and identifying flavours and they continue to use such skills in their professional life. Consequently, it seemed possible that they would adopt a more analytic attitude than controls when asked to rate the sweetness or sourness of the kind of solution used in the present study. Such a result would support the hypothesis that odour–taste interactions take place at a relatively high perceptual level. On the other hand, Auvray and Spence (2008), for example, have argued that these interactions take place at a low level that is impervious to top-down influences, as discussed further in Section 9. In this case chefs’ judgements would not be expected to differ from those made by non-professionals.

There appears to have been only one previous study that has investigated the sensory abilities of culinary professionals. Hirsch (1990) asked chefs from restaurants that were considered high in culinary excellence to participate in a study that explored their olfactory and gustatory abilities. The chefs were given tests on odour detection, odour identification and odour recognition. They also received a test that looked at their ability to taste sweet, sour, salty and bitter tastes. Out of the 10 chefs tested, six chefs showed superior olfactory ability, three below normal and one borderline. Seven chefs scored poorly on gustatory ability. Overall, there was no indication that in general chefs acquire special sensory abilities. However, this study did not obtain any data bearing on the current question of interest; namely, whether chefs tend to have superior analytic ability with respect to distinguishing between the contributions of gustatory and olfactory inputs when judging food- or drink-related flavours.

1. Experiment 1: Odour-modulation of taste perception in restaurant employees

This experiment asked whether chefs would perceive mixtures of odours and tastes differently from controls with relatively little culinary experience. Participants judged the tastes of a set of sweet and sour solutions to which either a sweet-smelling, sour-smelling or no odour had been added. As detailed below, the design allowed assessment of sweet enhancement, sweet suppression, sour enhancement and sour suppression effects in chefs, as well as in a control group of participants who worked in the same establishments, but not in the kitchens. We predicted that some, if not all, of these odour-induced modulations of taste judgements would be less evident in chefs than in controls.

2. Method

2.1. Participants

Of the 15 Sydney-based chefs (14 males and 1 female) who participated in the experiment, 10 were employees of the Hotel Intercontinental and five were employees of the Royal Sydney Yacht Squadron. Their mean age was 36.9 years and their mean length of professional experience was 18.9 years. The 17 control participants were employees from these establishments who were not chefs and had no professional training related to food preparation. Three of the controls, but none of the chefs, were excluded from data analysis due to apparent failure to comply with the instructions; this was indicated by these three rating sucrose as more sour than citric acid. Thus, results are reported for only the remaining 14 controls (8 males and 6 females) whose mean age was 33.1 years.

Participants were recruited by written request that outlined the procedure and were asked not to volunteer if they had a current respiratory infection. Otherwise they gave written consent. Participants were tested in groups of 1–4 in space set aside in their workplace.

2.2. Materials

The colourless solutions were presented in 29.5 ml transparent disposable sample cups, while water was presented in 236 ml (8 oz.) white polystyrene cups. The samples were placed on plastic place mats with printed numbers corresponding to the trial sequence. The rating scales and questionnaire were on paper.

2.3. Solutions

The tastes and odours selected for the study are shown in Table 1. Concentrations of sucrose and citric acid in tap water were chosen to produce a range of tastes from mildly sweet to mildly sour. Caramel and citral were used as the sweet and sour odours at concentrations chosen on the basis of pilot experiments using university students. These experiments established that at these concentrations in water neither caramel (16 participants) nor citral solutions (17 participants) had detectable taste properties, in that, when participants wore a nose peg, the taste ratings for these solutions were no different from those for water. Eight solutions were made by adding either caramel or citral to the four taste solutions shown in Table 1, while the remaining four had no odorant added. The solutions were freshly made each day and presented at room temperature.

2.4. Procedure

A 10-ml sample of each solution was prepared for each participant. These twelve samples were arranged into sequences containing three successive blocks of four samples, where each block contained at least one plain solution and no more than two caramel or two citral solutions. Six versions of these 4-sample blocks were produced and these were allocated to participants so as to counterbalance against possible sequential effects.
Participants were first asked to read an information sheet, sign a consent form and fill out a questionnaire. They were advised that all products were harmless and commercially available and were also told that they would need to taste and swallow each of the samples in front of them as though they were tasting wine, that is, paying close attention to the taste’s characteristics. They were then given the 12 solutions at 1-min intervals. After drinking each sample, participants filled out four 21-point linear rating scales in the following order: Overall Intensity (0–20, anchors: None, Extremely Strong), Sweetness (0–20, anchors: None, Extremely Sweet), Sourness (0–20, anchors: None, Extremely Sour) and Pleasantness (-10 to 10, anchors: Extremely Dislike, Indifference, Extremely Like). A rating was indicated by circling the appropriate number on the scale. After completing their ratings of a sample, participants were asked to drink some water and to swish the water around in their mouths before swallowing. This was done to cleanse the palate. The experimenter timed the 1-min interval between sampling, telling participants when to sample the next solution.

After they had rated the taste of all twelve solutions, participants were asked to sniff a caramel and a citral solution and rate each on the same four scales used for the taste ratings. There was again a 1-min interval between each sampling. Finally, the aim of the study was explained to participants and they were encouraged to ask questions, but not to discuss it with their colleagues until the study had been completed.

These procedures were approved by the University of Sydney Human Ethics Committee.

2.5. Data analysis

Ratings of the six sucrose solutions were analysed separately from those of the six citric acid solutions and the four ratings for each solution were also analysed separately. For each set of solutions and rating scale, e.g. the sweetness ratings of sucrose solutions, a 3-way ANOVA was applied to the ratings, with Group (Chefs vs Controls) as the between-subject factor, with Concentration (High vs Low) and Odour (Caramel vs No odour vs Citral) as the within-subjects factors. The alpha level for a significant effect was set at 0.05 for all analyses, including those in Experiment 2.

3. Results

3.1. Sweetness ratings

Sweetness ratings are shown in the three panels of Fig. 1. It may be seen that chefs and controls gave almost identical ratings, whether the solutions were plain (top panel), had caramel added (middle panel) or had citral added (bottom panel). Analysis of these ratings revealed both a sweetness enhancement effect in that both chefs and controls rated the sucrose solutions to be sweeter when caramel was present, $F(1,27) = 13.61$, and caramel also increased the sweetness of the citric solutions, $F(1,27) = 19.94$, both $p < .001$.

The only effect of citral that was detected was the unexpected one of increasing sweetness ratings for the citric solutions, $F(1,27) = 7.48$, $p < .025$. Reassuringly, the high concentration of sucrose was rated as sweeter than the low concentration, $F(1,27) = 28.80$, $p < .001$. There was no main effect on sweetness ratings of Group or interaction involving this factor for either the sucrose or the citric acid solutions, largest $F(1,27) = 3.80$, and thus no indication that chefs differed from controls in the degree to which the two odours influenced their judgements of sweetness.

3.2. Sourness ratings

As may be seen in Fig. 2, there was also little difference between chefs and controls in terms of their sourness ratings. As for the effects of adding the two odours, the addition of caramel to sucrose solutions had no effect on the sourness of these solutions, but this odour did produce a sourness suppression effect in that sourness ratings of citric acid solutions were lower when caramel was present, $F(1,27) = 6.12$, $p < .025$.

The effect of citral was more complicated. When added to the sucrose solutions, it increased sourness ratings, $F(1,27) = 12.66$, $p < .01$, but – paradoxically – citral decreased sourness ratings of the citric acid solutions, $F(1,27) = 6.01$, $p < .025$. The effects of concentration were significant both for the sucrose solutions, i.e. the
higher concentration was rated as less sour, $F(1,27) = 4.58, p < .05$, and for the citric acid solutions, i.e. the higher concentration was sourer, $F(1,27) = 9.56, p < .01$.

As with the sweetness ratings, there was no main effect on sourness ratings of Group and no interaction involving this factor, except for a 3-way interaction between Group, Concentration and Odour for sourness ratings of the sucrose solutions, $F(1,27) = 5.24, p < .05$. Since it is difficult to identify the nature of this interaction from the way that the sourness data are displayed in Fig. 2, the relevant mean ratings are shown in Table 2. These indicate that for the chefs citral increased sourness ratings of the High but not of the Low sucrose solution, whereas for the controls citral increased sourness ratings of the Low but not of the High sucrose solution.

3.3. Overall intensity and pleasantness ratings

Similar analyses to those for sweetness and sourness ratings revealed that adding caramel and citral increased overall intensity ratings for the sucrose solutions, $F(1,27) = 14.46$ and $32.37$, respectively, both $p < .001$, but had no detectable effect on such ratings of the citric acid solutions. The only other effect was that the High concentration of citric acid was rated as more intense than the Low concentration, $F(1,27) = 28.47, p < .001$. Most importantly there were no main effects of Group or interactions involving this factor, largest $F(1,27) = 2.44$.

The only effect detected for the pleasantness ratings was that participants found the High concentration of citric acid less pleasant than the Low concentration, $F(1,27) = 10.17, p < .01$. Yet again, there was no main effect of Group or interaction involving this factor, all $F$s < 1.

3.4. Sniff test ratings

These ratings were taken at the end of the experimental procedure. The main aim was to test whether a participant’s rating of the sweetness or sourness of caramel and citral when perceived orthonasally would be related to the degree that the odours, when perceived retronasally, would modulate this person’s perception of the sucrose and citric acid solutions to which the odours had been added. Correlation coefficients were calculated, for example, between the perceived sweetness of caramel when sniffed and the size of the sweetness enhancement effect, calculated as the difference between the average sweetness rating for the two sucrose solutions when caramel was added and the average rating for the two solutions when no odour was added. The only significant outcome of these analyses was that the perceived sourness of citral when sniffed correlated with the degree that this odour reduced the perceived sweetness of the sucrose solutions; i.e. the extent to which a participant displayed sweetness suppression, $r = .54, p < .01$. None of the remaining three coefficients were significant, greatest $r = .27$.

4. Discussion

The main questions addressed by Experiment 1 were: do retro-nasal odours modulate the perception of tastes by professional chefs? And, if so, does the degree of modulation differ from that shown by control participants? The answer to the first question is clearly that the taste ratings of the chefs tested here were indeed sensitive to the addition of odours. As summarised in Table 3, their ratings showed the sweetness enhancement effect, in that the caramel odour increased sweetness ratings of the sucrose solutions to which it was added, and sourness suppression, in that the same odour decreased sourness ratings of the citric solutions. As for the second question, hardly any difference was detected between chefs and controls.

Across participants, sweetness ratings of caramel when sniffed did not correlate with the degree of sweetness enhancement of sucrose ($r = .06$) or sourness suppression of citric acid ($r = .27$). Although past research found that smelled sweetness is a strong predictor of enhancement and suppression effects, this was based on correlations across a number of odours, not across participants (Prescott, Stevenson, & Boakes, 1996). Across participants, sourness ratings of citral when sniffed did correlate with the degree of sweetness suppression ($r = .53, p < .01$), even though an overall sweetness suppression effect was not found.

An incidental finding from the intensity ratings was that the addition of both citral and caramel increased the perceived intensity of the sucrose solutions, but no such effect was detected when these odours were added to the citric solutions. This is inconsistent with the conclusion reached by Murphy and Cain (1980) that the perceived magnitudes of an odour and of a taste summate when they are combined and this is independent of whether the combination is judged ‘harmonious’, as with the citral-sucrose combinations in their study, or ‘dissonant’ as in the citral-saline combinations that they also included (cf. Hornung & Enns, 1986).
5. Experiment 2: Food- and drink-associations to caramel and citral

In Experiment 1 citral produced the expected increase in the sourness of sucrose solutions, but when added to citric acid it increased their sweetness and decreased their sourness. Furthermore, in the final odour test, the sourness ratings of citral correlated only with the degree to which it reduced sweetness of sucrose.

To the extent that the taste properties of odours depend on the associations they have acquired for an individual (Stevenson & Boakes, 2003), the mixed effects of citral suggest that this evokes quite disparate associations. Thus, this second experiment was designed to test the prediction that citral when sniffed will evoke associations of both sour and sweet foods and drinks, whereas the associations to caramel will be uniformly sweet.

6. Method

6.1. Participants

Since access to chefs had become difficult to obtain, for this second experiment 18 academic and general staff employed by the University of Sydney were recruited. They consisted of 10 males (mean age: 38.8 years) and 8 females (mean age: 40.1 years).

6.2. Solutions and materials

Each participant was presented with four solutions, two containing 0.75% citric acid and two containing 3% sucrose. For each of these two base solutions 0.04 g/l citral was added to one and 3.2 g/l caramel was added to the other. Thus, the odour concentrations were identical to those used in Experiment 1, while the concentrations of the citric acid and sucrose solutions were the means of the ‘High’ and ‘Low’ concentrations used in that experiment. The solutions were presented in small plastic cups, each containing 10 ml of a solution. In addition, a large plastic cup contained tap water.

6.3. Procedure

Fresh samples were poured into the small cups for each participant. These were placed on a tray, along with the large cup of water, and carried to a participant’s office where the test, lasting from 10–15 min, was carried out. In the initial sniffing test participants were first asked to sniff a solution, report what food or drink ‘first comes to mind’, and then rate this food or drink on a 11-point scale for: (a) Sweetness, 0 (Anchor: ‘Not at all sweet’) to 10 (Anchor: ‘As sweet as anything can be’); and for (b) Sourness 0 (Anchor: ‘Not at all sour’) to 10 (Anchor: ‘As sour as anything can be’). They were then asked to sniff the same solution a second time and report any food or drink that now came to mind that was different from the first one. Afterwards they rated this second food/drink for sweetness and sourness.

This 2-trial procedure was repeated for each of the samples, with participants sniffing the water in between sniffing a sample. Thus, by the end of this stage participants were required to have produced four different associations to each odour and to have rated each of the food-drink associations for both sweetness and sourness. The instructions emphasized that the ratings were of the different foods and drinks that came to mind, and that participants were not to rate the odours themselves. Also, it was explained that ‘food or drink’ was to be understood in a broad sense so that it included, for example, confectionery and items ingested for medicinal purposes.

In the sipping test that followed on immediately, participants were asked to sip each solution and then report ‘what food or drink first comes to mind; this can be the same or different from an association you reported when simply sniffing the solutions’. Participants then rated the food or drink ‘that had come to mind’ for sweetness and sourness, as before.

The sequences of samples were arranged so that the odours were alternated and sequences were completely counterbalanced across participants, e.g. half the participants were given caramel first and half citral first. This yielded eight possible sequences. Participants sipped some water in between sipping the samples.

6.4. Data analysis

Analyses of data from the sniffing tests consisted of repeated measures t-tests that compared various ratings of caramel with those of citral. As detailed below, 2 × 2 ANOVAs were applied to data from the sipping tests.

7. Results

In the sniffing test two participants were unable to report four different associations to each of the odours and consequently their data were excluded from the analysis. Thus, the results that follow are for the remaining 16 participants, with two allocated to each of the eight sequences.

Data from the sniffing test confirmed that foods and drinks associated with caramel were consistently rated as tasting sweeter (mean: 7.33, on the 0–10 scale) and less sour (mean: 0.44) than those associated with citral (sweetness mean: 4.17; sourness mean: 4.92), t(15) = 5.67 and 9.64, respectively, both ps < .001. Of much more interest was the variation in these ratings, measured as the range of sweetness and of sourness ratings for the four different associations that each participant produced. As predicted, the range of sweetness ratings for caramel-associated foods or drinks (mean: 2.44) was smaller than the sweetness range for associations evoked by citral (mean: 4.75), t(15) = 3.08, p < .01. Similarly, the range of sourness ratings for caramel-associated foods or drinks (mean: 0.81) was smaller than the range for citral associations (mean: 5.0), t(15) = 7.96, p < .001. The latter wide range resulted from associated foods or drinks that varied, for example, from extremely sour lime fruit, through moderately sour lemon-grass to a sweet lime cordial drink.

Sweetness and sourness ratings from the sipping test were subjected to separate 2 × 2 ANOVAs, with taste (sucrose vs citric acid) as one factor and odour (caramel vs citral) as the other. Unsurprisingly, foods and drinks associated with sucrose elicited higher sweetness ratings and lower sourness ratings than those associated with citric acid, F(1,14) = 6.22, p < .05, and 6.35, p < .025.
respectively, while – more interestingly – foods and drinks associated with solutions containing caramel elicited higher sweetness ratings and lower sourness ratings than those associated with solutions containing citral, \( F(1,14) = 5.42, p < .05 \), and \( 16.23, p < .01 \), respectively. No interactions were detected, both Fs < 1.

8. Discussion

The main effects of odours found here are consistent with the results from Experiment 1, where the solutions themselves were rated. Some of the individual differences in odour ratings were understandable in terms of participants' individual histories with foods, as revealed by subsequent discussion. For example, citral evoked lemongrass as an association apparently only in participants very familiar with Thai cuisine, while caramel evoked a non-sweet association only in a participant who recalled a lamb stew from his Serbian childhood. These observations suggest an explanation for the single difference between the chefs and the controls in Experiment 1, whereby citral increased chefs' sourness ratings of the High but not of the Low sucrose solution, but tended to increase controls' sourness ratings of the Low sucrose solution. It seems plausible that the chefs were familiar with a different range of foods and drinks with citrus-like flavours from the range experienced by the controls.

9. General discussion

As discussed in the Introduction, because of chefs' extensive – and highly active – experience with food-related odours and tastes, it was possible that their perception of tastes would be less affected by the presence of retronasal odours in the solutions. Finding only a very minor difference between chefs and controls supports the view that smell-taste confusion of the kind demonstrated in Experiment 1 is 'cognitively impenetrable' (Stevenson & Case, 2003). On the other hand, it is possible that, if these participants had been told that some solutions were mixtures of tastes and smells and asked to adopt an analytic attitude, namely, by concentrating on the tastes and ignoring the odours when making their ratings, sizeable differences between chefs and controls might have been obtained.

In their review of research on multisensory interactions related to flavour perception, Auveray and Spence (2008) discuss the distinction between analyses based on distinctions between sensory receptors – the 'modal' approach – and those based on information related to particular objects or events in the world that can be obtained from a variety of sense organs – the 'supramodal' approach. Following Gibson (1966), they argue that perception of flavours is best understood in terms of the supramodal approach; we judge the flavour of a food or drink without reference to the type or location of the various sense organs – tactile and trigeminal, and even eyes and ears, as well as taste and olfactory receptors – that can contribute to our perception of the flavour of whatever is currently in our mouths. In addition to the direct effects of current sensory inputs, perception of a flavour is also affected by the associations that these various sensory inputs evoke, associations that are normally automatic and implicit. The present results are consistent with such an approach and indicate that it applies as much to culinary professionals as to non-professionals.

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