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The Acquisition of Taste Properties by Odors

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Certain odors are routinely described as smelling sweet. This phenomenon may result from the co-occurrence of such odors and tastes outside the laboratory. Experiment 1 tested this possibility by pairing a selected odor with sucrose and another with citric acid in a masked design, using 24-h spaced sessions, preceded and followed by ratings of the odors' taste attributes when sniffed and when rated with tastes in solution. Following conditioning, the odor paired with sucrose smelled sweeter and with citric acid, sourer. In Experiment 2, contingency awareness was examined using a recognition measure, in an otherwise similar design. Again, odors smelled sweeter and sourer postconditioning. Contingency aware and unaware subjects did not differ in performance. Experiment 3 examined an exposure account of these changes, using a similar paradigm to Experiment 1, but with no exposures to sucrose or citric acid. No changes in odor taste attributes were observed. Overall, these findings demonstrate that associative learning, irrespective of awareness, has an important role in the acquisition of odor–taste qualities.

People commonly attribute the smell of an ingested food to the taste system rather than to the olfactory system (Rozin, 1982). Psychophysical studies of these two chemical senses have consistently found what is sometimes called the "taste–smell illusion" whereby subjects report a taste quality in ingestants that contain only an odorant (e.g., Burdach, Kroeze, & Koster, 1984). In such cases the dependence of the illusory taste on the sense of smell is demonstrated by the simple procedure of having subjects pinch their noses, whereupon the "taste"

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disappears (e.g., Murphy & Cain, 1980). What may be seen as a different kind of perceptual confusion arises when subjects attribute taste qualities to a substance that is a pure odorant, even when the latter is sniffed. The example of interest here is the perceived sweetness of many odors (Dravnieks, 1985).

Odors perceived as sweet can enhance the sweetness of a sucrose solution to which they are added. This sweetness enhancement effect was first reported by Frank and Byram (1988) in a study where strawberry odorant was added to sucrose solutions of varying concentration (Experiment 1) and found to increase the sweetness of the solutions, as measured on a 21-point category scale. Subsequent experiments established that the effect was not obtained when a peanut butter odorant was added to sucrose (Experiment 2), that strawberry did not enhance the saltiness of sodium chloride solutions (Experiment 3), and that the sweetness enhancement effect found in Experiment 1 disappeared when subjects pinched their noses. Subsequently, Frank, van der Klaauw, and Schifferstein (1993) referred to an unpublished experiment in which the effect was also found using a sweetness matching procedure.

In discussing the possible basis for the perceived sweetness of certain odors Frank and Byram (1988; p. 449) speculated that this could arise from associations with sweet-tasting foods. This provided the starting point for the present experiments. Our main aim was to discover whether such associations could be established in a controlled laboratory setting by adding unfamiliar odorants, with relatively low initial sweetness ratings, to a sucrose solution. It was predicted that repeated exposure to such a compound would increase the perceived sweetness of the odor.

To prevent the confusion over terminology that can easily arise in this setting, the convention adopted here is to use *odor* to refer to the sensation arising from active sniffing, *flavor* to refer to the olfactory sensation arising from ingestion of a substance that may or may not include a taste component, and *taste* to a substance such as a sucrose solution or saline that includes no significant odor component.

What appear to be the only comparable experiments to those reported here have investigated flavor–flavor conditioning in human subjects. These have been based on extensive research using rats which have demonstrated changes in hedonic response to previously neutral flavors that have been mixed with either inherently distasteful or pleasant tastes (e.g., Fanselow & Birk, 1982; Holman, 1975). In the first experiment of this kind using human subjects, Zellner, Rozin, Aron, and Kulish (1983) reported enhanced liking for tea flavors that had previously been mixed with sucrose solution, relative to flavors that been sipped when unsweetened. Subsequently Baeyens, Eelen, van der Bergh, and Crombez (1990a) reported some evidence that flavors which had been mixed with an unpleasant taste (Tween 20) were disliked more in a subsequent test, but found no convincing evidence for increased liking for flavors that had been previously mixed with a sucrose solution.

The principal way in which the present experiments differ from the two above is the use of taste attribute ratings (e.g., sweetness) as the main dependent variables. However, since we were interested to see whether the conditioning procedure might also produce hedonic changes, this measure was included as well. The procedures used by Zellner *et al.* (1983) and by Baeyens *et al.* (1990a) consisted of a conditioning and a test phase, within a single session. We decided to use an approach more akin to that typically taken in studies using animal subjects and required subjects to attend for a series of five sessions at least a day apart. This choice of a spaced trial procedure, rather than the massing used in previous studies, e.g., the intertrial interval was only 30 s in Baeyens *et al.* (1990), was adopted for a number of reasons. Most importantly, we wished to reduce the likelihood that subjects when tested would explicitly remember particular conditioning trials and also to reduce the likelihood that on the posttest they would remember the ratings they had given on the pretest. The latter possibility was also reduced by requiring, in both pre- and posttests, ratings of each sample along a number of different dimensions and in conditioning sessions, by interspersing dummy trials in which subjects made judgments of flavors and tastes unrelated to the main aim of the experiment. Another reason for spacing trials was to generate, as far as we could in a laboratory setting, conditions that would resemble exposures to such pairings in the outside world.

The concern to reduce explicit recall of specific events prior to the posttest stemmed from our interest in whether any change in odor perception that was detected could occur under conditions in which subjects were unaware of the contingencies embedded in the procedure. To this end the primary purpose of the experiments was concealed from subjects prior to final debriefing. The dummy trials were expected to increase the credibility of the masking task, which was described as concerned with changes in the perception of a range of flavors.

It seemed likely that the outcome of the experiments might depend on careful choice of the target odorants. Consequently, the perceived attributes of six potential stimuli were measured systematically prior to undertaking the main experiments and this procedure is described first. Experiment 1 then used two odors, selected out of the six, and paired one odor with sucrose and the other with citric acid. Two odors were used so that each could act as the control for the other. The rationale for pairing the other odor with citric acid rather than water was that during the initial phase of the experiment all flavors were to be presented with all tastes to establish baseline ratings prior to conditioning. If a control odor had been paired with water and a test odor with sucrose, the control odor would have been presented with sucrose in this pretest. If perceptual changes of odor/flavor attributes can take place in one trial, this would render the control procedure ineffective. By using citric acid instead of water, it was hoped to erase, by interference, any effect of pairing either odor with sucrose or citric acid during the baseline rating phase. Though we expected the odor paired with sucrose to increase in perceived sweetness, the inclusion of an odor paired with citric acid would also allow us to see if the same hypothesized effects generalized to other taste–flavor/odor combinations.

METHOD

Selection of Odor Stimuli

Twenty CSIRO staff, 11 male and 9 female, none suffering from colds or other respiratory infections, volunteered to participate. Odor stimuli were presented in new plastic polypropylene 250-ml bottles each containing 50 ml of odorant in solution. All bottles had contained their odorant for at least 1 week prior to testing and odors were replenished on the morning preceding every test day. All odorants used in the study were approximately matched for intensity on the basis of previous pilot work. Odors were initially selected to be neither particularly pleasant nor unpleasant and to be relatively novel. The odors chosen for selection testing were: Lychee, Taro, Snow Milk, Pearade, Water Chestnut, Maracuja (Quest), and a Water blank.

On arrival, subjects were presented with written instructions detailing the task and the use of the rating scales. Subjects were then shown how to smell the odors. This involved placing the 3-cm plastic spout of the bottle (opening diameter 4 mm) approximately 4 cm below the nose and vigorously squeezing the plastic bottle while sniffing. Subjects were told to take as long as they wanted to smell the odor as they would not be able to smell it again once they were handed the rating sheet. This is because extra sniffing beyond the first sniff provides the subject with little further information, only confirmation (Laing, 1983). Subjects were then presented with the first test odor out of the series of seven. The order of presentation was determined by Williams squares so that every odor had an equal probability of being followed by any other odor. The rating sheet contained four 153-mm visual analog scales (VAS) in the following order, Liking/Disliking (anchors: Dislike extremely, Like extremely; plus a central marker; Indifference), Saltiness, Sourness, and Sweetness (anchors: None, Extremely strong). Subjects were not given specific definitions of what "sweet," "salty," or "sour" might mean in the context of judging odors rather than tastes. However, if a subject did ask, they were given previously agreed definitions which were: for sweetness, "A sweet smell similar to that of freshly baked cakes," for sourness, "A sour smell similar to that of vinegar"; and for saltiness, "A salty smell similar to that of sea air." Subjects appeared to have little difficulty in applying sweet or sour ratings to the odors. The salty rating was primarily included, along with the water blank, to screen out subjects who rated all the odors, or nonodors in the case of water, as containing every possible rating category. None of the odors would normally be described as at all salty, possibly excepting Taro. Finally, subjects were asked whether they were familiar with the odor, "Before today, had you ever smelled THIS odor before?"; the available responses were, Yes, Unsure, No. All odor selection tests and other studies reported here were performed in well-ventilated, air-conditioned rooms.

Of the 20 subjects who completed the study, 2 were excluded as they rated a large number of the stimuli as smelling moderately to strongly salty. The remaining subjects VAS scores, varying from 0 to 153, were converted into percentages for ease of comprehension. Familiarity ratings were converted arbitrarily into numeric scores, so that "No" = 3, "Unsure" = 2, and "Yes" = 1, which were then treated as ordinal. All reported statistical comparisons used two-tailed probabilities and the 5% significance level, unless otherwise stated. These same conventions were employed throughout the reported experiments.

The means from the data for each odor were examined and the two odors that best fulfilled the final selection criterion, of being neither particularly pleasant nor unpleasant, preferably novel, and neither strongly sweet nor sour, were selected. These were Lychee (LY) and Water Chestnut (WC) odors. The characteristics of all the odors are described in Table 1. The other odors were excluded on the following grounds: Taro, as smelling moderately unpleasant; Pearade, Snow Milk, and Maracuja, as too sweet.

EXPERIMENT 1

Method

Subjects. Twenty-two University of Sydney first year undergraduates, none suffering from colds or other respiratory infections, took part in the experiment as part of their course requirements. The experiment was advertised as a "Flavor judgment experiment."

Stimuli. The two odor stimuli, selected in the preceding experiment were Walter Chestnut (WC; 0.03 g/liter in distilled water) and Lychee (LY; 2.0 g/liter in distilled water). The same concentrations were also used when the odors were mixed with taste stimuli and presented as flavors. The taste stimuli were 0.3 *M* (10.3% w/v) Sucrose, 0.0075 *M* (0.16% w/v) Citric acid, and 0.043 *M* (0.25% w/v) Sodium Chloride (Univar), all in distilled water. Pear odor (Quest) was used only during the conditioning sessions at 0.07 g/liter in distilled water. All odors were presented in the manner described for the odor selection experiment. Odors were always kept in the same bottles and bottles were "cured" with the odor for at least 4 weeks preceding the first experiment. Bottles were sealed after use and the contents were replenished on the morning preceding any day that involved

TABLE 1
Odor Selection Experiment: Characteristics of the Selected and Unselected Odors

Odor	Liking	Sweet	Sour	Salty	Familiarity
Water Chestnut[a]	49.6 (23.3)	30.3 (29.6)	15.1 (24.0)	2.0 (3.1)	Unsure/Yes
Lychee[a]	60.5 (22.3)	49.7 (29.0)	23.3 (22.7)	2.1 (3.6)	Yes
Pearade	70.3 (20.7)	63.7 (28.8)	18.2 (29.2)	1.9 (3.3)	Yes
Snow Milk	68.4 (20.4)	66.2 (16.9)	7.7 (13.3)	0.9 (1.5)	Yes
Maracuja	76.8 (13.8)	77.4 (16.6)	15.9 (24.1)	1.6 (2.5)	Yes
Taro	35.6 (24.4)	19.1 (25.8)	22.1 (27.9)	14.7 (19.3)	Unsure

Note. All values are mean ratings, except for familiarity where medians are reported. Standard deviations are in brackets.

[a] Selected odors.

smelling the odors. All taste stimuli were presented in aliquots of 10 ml, contained in 35-ml translucent plastic cups, which were filled on the morning of the experimental session. Only taste stimuli containing sucrose were refrigerated. All stimuli were tasted at room temperature.

Procedure. Each subject attended five sessions: pretest, three conditioning sessions, and posttest. The procedure is summarized in Table 2. On arrival at the first session, subjects were handed written instructions which briefly described the first part of the pretest and outlined the use of the rating scales. A blank rating scale was attached to the bottom of the instruction sheet. When subjects had read the sheet the experimenter drew their attention to the differences between the liking and intensity rating scales and made sure that they had read the two familiarity questions at the bottom of the example rating sheet.

Subjects were then briefed as to how to smell the odors, which the experimenter demonstrated by using an empty sniffing bottle. Subjects were then presented with either the LY or the WC odor bottle, marked with the numbers 5 and 1, respectively, for purposes of identification. The order of presentation was arranged so that an equal number of subjects received each odor first. After smelling the odor, the subject handed it back and was then given the first rating sheet. This consisted of four 153-mm VAS in the following order; Liking/Disliking, Overall Intensity, Sourness, and Sweetness. The anchors were the same as those described in the selection of odors experiment. Following this subjects were asked, "Before today, had you EVER smelled a SIMILAR odor to this before?"; available responses: Yes, Unsure, No. They were then asked, "Before today, had you EVER smelled THIS odor before?"; available responses: Yes, Unsure, No. On completion of the rating sheet the same procedure was followed for the second odor.

In the second part of the pretest, six taste and flavor stimuli were presented; Sucrose alone, Sucrose and LY, Sucrose and WC, Citric acid alone, Citric acid and LY, and Citric acid and WC. All stimuli were visually identical. The order

TABLE 2
Diagrammatic Summary of the Procedure for Experiment 1

Day 1 Pretest	Conditioning days: Day 2 Day 3 Day 4	Day 5 Posttest
(1) Smell LY and WC odors and rate them.	(1) On each day the same task is repeated. Subjects sample 18 solutions, 3 of which are flavor plus sucrose and 3 the other flavor plus citric acid.	(1) Smell WC and LY odors and rate them.
(2) Taste and rate six solutions of flavors and tastes.		(2) Taste and rate six solutions of flavors and tastes.

of presentation was again determined by Williams square. Before tasting the solutions, subjects were handed a new instruction sheet, which briefly detailed the task and outlined the rating scales to be used. The experimenter then reiterated these instructions telling subjects to immediately pour all the test solution into their mouth when the solution was handed to them, to roll it around and then expectorate into the receptacle provided, and then complete the rating sheet. After this, they were instructed to thoroughly rinse their mouths with mineral water. This time, the rating sheet contained only the four VAS described above, but with the sweetness rating preceding the sourness rating. This change of order was pointed out to subjects in an attempt to get them to read the scale titles before responding. Rating the two odors and the six solutions constituted the pretest (session 1).

At least 1 day after the pretest, subjects returned for the first of the three conditioning sessions, each of which was separated by a minimum of 24 h. Each conditioning session contained six trials, each trial consisting of 3 solutions (i.e., 18 solutions per session). Of the six trials on any conditioning session, two were conditioning trials, consisting of a flavor paired with sucrose and the other flavor paired with citric acid. Which flavor (LY or WC) was paired with which taste depended on which condition the subject had been previously assigned to (i.e., LY–sucrose and WC–citric acid or LY–citric acid, WC–sucrose). The remaining four trials comprised the masking task and always contained the following elements: one trial each of: saline, saline, water; water, water, saline; pear flavor, pear flavor, water; and water, water, pear flavor. The order of presentation of all trials, conditioning and masking, was determined by Williams square, while the position of the odd stimulus in the masking trials was systematically varied on each conditioning session.

On the first trial, before tasting its three solutions, the experimenter repeated the instructions. Subjects were then given a rating sheet and asked to sample and expectorate the solutions, one at a time, from left to right and to select which solution was different out of the three (the "Triangle" or "Oddity" test). Subjects were informed that they should expect the Triangle tests to vary in difficulty from very hard to discriminate to fairly hard. The code of the different or odd solution was then marked down on the rating sheet by the subject. Subjects were then instructed to rinse their mouths with mineral water, which concluded the trial. The next trial then began, using a new rating sheet, but with the same procedure as described above. When the six trials had been completed, this constituted a conditioning session.

In total, subjects experienced three conditioning sessions. The only change in the second and third conditioning sessions was that the order of presentation of the six trials was again varied by Williams square and that the different stimulus in each of the four masking trials, which was always on the left on the first conditioning session, was in the center on the second session and on the right on the third.

At least 24 h after completing the last conditioning session, subjects returned for the posttest. This was identical to the pretest, with the following exceptions. The order of presentation of the odors in the smelling task was reversed, so that if LY had been smelled first and WC second in the pretest, LY was now smelled second and WC first in the posttest. Also, the order of the stimuli in the taste–flavor test was again varied by Williams squares. After subjects had completed the smelling and tasting tasks of the posttest, they were then asked the following question: "As well as to collect information of people's perception of flavors and to see how these change with repeated exposure, there was another aim to the experiment. What do you think this might have been?." Subjects were then asked to rate, on a scale of 1 (Very certain) to 4 (Very uncertain, guessed, no idea) how sure they were of their response. On completion of the posttest subjects were then debriefed by the experimenter and asked not to betray the purpose of the experiment to anyone else.

Results

Nineteen of the 22 subjects completed the experiment, 1 subject having not returned after the pretest and 2 subjects having failed to return for their second conditioning session. Of the remaining 19, it was decided to eliminate the data of 3 subjects on the following basis. On the pre- or posttest, any subject rating the sucrose solution as more sour than sweet or the citric acid solution as more sweet than sour was eliminated. The rationale for this was that either the subject had a defective sense of taste or had not paid adequate attention to what he or she had been rating. Of the 16 included in the analysis, 9 had been exposed to WC–sucrose and LY–citric acid and 7 to LY–sucrose and WC–citric acid. Of these 16, 12 were female and 4 male. All subjects completed the posttest on the day following the last conditioning session.

Odors. Although a simple difference score of pre- to posttest ratings for the "taste" rating associated with the target odor (i.e., the sweet rating for the LY odor for a subject who received LY–sucrose pairings) might be thought adequate to detect any lawful change in odor perception, it is necessary to take into account any changes in ratings that would have occurred regardless of the odor (flavor) sucrose pairings. For this reason, for each subject, a difference score was calculated between the change in sweetness for the odor paired with sucrose and the change in sweetness for the odor paired with citric acid. The difference between these two scores provides our measure of perceptual change, as it takes into account any changes in sweetness that may have occurred as a result of repeated pairing to a taste other than sucrose. The same measure was also used for sourness ratings. The results are depicted in Table 3.

Ratings for sweetness increased significantly for the odor paired with sucrose and decreased significantly for the odor paired with citric acid. Overall, a change of about one-third of the rating scale length occurred, strongly supporting the contention that the perception of sweetness is enhanced for an odor when a sweet taste co-occurs with that particular odor (see Fig. 1). Though the two odors differed in initial ratings of sweetness on the pretest (LY: mean 62.4; WC: mean

TABLE 3
Experiment 1: Changes in Sweetness and Sourness for the Target Odors and Flavors, Pre- to Posttest, Expressed as Mean Difference Scores

Difference score (Posttest minus pretest)	Odors		Flavors	
	Mean (*SD*)	$t(15)$	Mean (*SD*)	$t(15)$
(1) Sweetness difference for sweet–odor pairing	18.9 (33.7)	2.24*	−2.5 (17.6)	0.57
(2) Sweetness difference for sour–odor pairing	−17.6 (29.4)	2.40*	−7.7 (13.7)	2.25*
(3) Net change in sweetness (1) − (2)	36.5 (53.8)	2.71*	5.2 (22.4)	0.92
(4) Sourness difference for sour–odor pairing	20.8 (33.8)	2.46*	0.9 (32.1)	0.11
(5) Sourness difference for sweet–odor pairing	−4.6 (24.5)	0.75	7.7 (35.0)	0.88
(6) Net change in sourness (4) − (5)	25.4 (43.8)	2.16*	−6.8 (37.9)	0.72

Note. All tests are one-tailed and significant where stated.
* $p < .05$.

34.8; $t(30) = 3.15$), there were no significant differences in the sweetness change scores between odors. Ratings of sourness also increased significantly for the odor paired with citric acid, though there was no significant change in sourness for the odor paired with sucrose. An overall change in sourness of about one-quarter of the rating scale was observed (see Fig. 1). Again, there were no differences between odors, in respect to the magnitude of sourness change observed for each odor, nor was there any significant difference in the sourness ratings given to them on the pretest (LY: mean 19.5; WC: mean 23.5). Finally, changes in sweetness ratings for the odor paired with sucrose correlated with changes in sourness ratings for the odor paired with citric acid (Pearson's $r = .66$, one-tailed).

Ratings of overall intensity and liking were examined by testing differences between pre- and posttest ratings. Ratings of overall intensity significantly increased between pre- and posttest for the odor paired with sucrose (mean difference = 18.2; $t(15) = 3.59$), but not for the odor paired with citric acid (mean difference = 5.4). Though LY was initially rated as more intense than WC (LY: mean 55.3; WC: mean 40.1; $t(12) = 2.62$), there were no significant differences between them in their change scores when compared on either the citric acid or sucrose pairings.

Liking ratings for the sucrose paired odor revealed no significant change in liking pre- to posttest (mean difference = −2.4). However, there was a nonsignificant trend for a decrease in liking for the odor paired with citric acid (mean difference = −7.0; $t(15) = 1.67$). Though LY recorded higher liking ratings initially than WC (LY: mean 70.3; WC: mean 48.8; $t(30) = 4.02$), the odors did not significantly differ when compared on change scores for either sucrose or citric acid pairings.

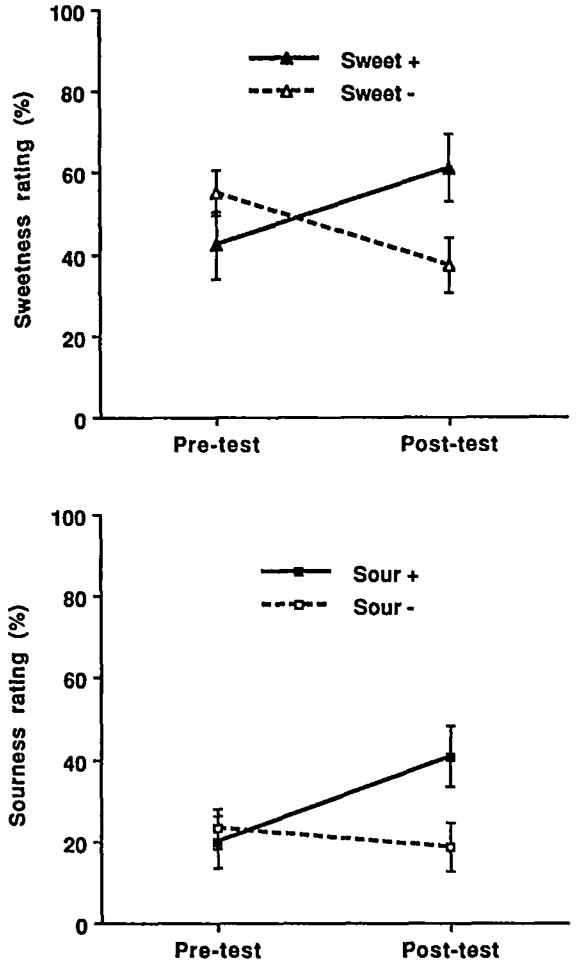


FIG. 1. (Top) Mean visual analog scale ratings on pretest and posttest of sweetness (0 = no sweetness), for the odor paired with sucrose (Sweet+) and for the odor paired with citric acid (Sweet−), in Experiment 1. (Bottom) Mean visual analog scale ratings on pretest and posttest of sourness (0 = no sourness), for the odor paired with citric acid (Sour+) and for the odor paired with sucrose (Sour−), in Experiment 1. Means are shown with standard errors.

On pretest, subjects were generally familiar with the odors, in that median responses for both WC and LY on the first familiarity question ("... EVER smelled a SIMILAR odor ....") were that they had. However, subjects were unsure as to whether they had smelled that particular odor before (second familiarity question, " ... EVER smelled THIS odor ...."). On posttest, median responses revealed that subjects now recognized that they had smelled these particular odors before (Wilcoxon signed rank test, WC, $T(10) = 9.5$ and LY, $T(10) = 8.0$, one-tailed). Odors did not differ in initial familiarity on either of the two questions.

The results reported so far revealed changes in the perceived sweetness of the odors, but not in their hedonic value. This might have arisen because the hedonic judgments were more variable. To examine this possibility we calculated the ratio of variance between odor sweetness and odor liking ratings for three sets of data: WC odor on pretest, LY odor on pretest, difference score of odor paired with sucrose pre- to posttest. In all cases the variances of the odor sweetness ratings were larger than the variances of the corresponding liking ratings, with the ratio being around 3. Briefly, it should be noted that this comparison could be weakened because of the difference in the nature of the two scales, namely, that half of the liking–disliking scale was for liking and half for disliking, therefore giving a more restricted range for responses when contrasted with the sweetness intensity scale.

Flavors and tastes. A comparable analysis was conducted on sweet and sour ratings of the taste flavor stimuli. For instance, for a subject who received LY–sucrose and WC–citric acid, a change score was calculated for sweetness ratings on the sweet LY flavor and for sweetness ratings on the sweet WC flavor. The difference between these two scores was then considered as the key measure of whether a change in taste/flavor perception had occurred. This calculation as to whether any change in the perception of sweetness or sourness of the flavor–taste mixtures had taken place was analogous to the strategy employed for the odor stimuli. Overall, no significant changes in sweetness or sourness were observed, though a significant reduction for sweet ratings of the flavor paired with citric acid was present (see Table 3). Ratings of overall intensity and liking were both analyzed in an analogous manner to the odor data and revealed no significant changes on any variable.

Debriefing. No subject identified the purpose of the experiment. More specifically, those who thought they knew believed it was as the title of the experiment suggested, to examine individuals' perceptions of flavors. Subjects were carefully interrogated by the experimenter to see whether they had been in communion with any other subject who had finished the experiment. No subject revealed any knowledge of the real purpose of the study.

Discussion

Experiment 1 provides the first evidence of a change in the perception of odors, as a consequence of pairings with sweet and sour tastes. Although there was generally symmetry between the changes observed for the sucrose and citric acid paired odors, there was one exception. Sweetness ratings for the odor paired with citric acid decreased, though there was no comparable change for the ratings of sourness for the odor paired with sucrose. The absence of any decrease in sourness may have resulted from a floor effect, in that initial ratings for odor sourness were much lower than for sweetness, thus giving more scope for sweetness to decrease and less scope for a comparable change in sourness to be detected. The data also revealed that subjects who changed their perceptions of one odor (e.g., increasing sweetness) also tended to show similar changes for the other odor (e.g., increasing sourness). This absence of independence between effects might suggest individual susceptibility to acquire such relationships and a consistent use of the rating scales.

The debriefings implied that the changes in odor perceptions had occurred independently of subject awareness of the purpose of the experiment. However, asking subjects in the manner used in Experiment 1 may be a weak way of examining this issue (Nisbett & Wilson, 1977), primarily as recall tests are less sensitive than those using recognition (Dawson & Reardon, 1973). For this reason, a second experiment was conducted, in a similar manner to the first, but employing on posttest a more searching examination of subjective awareness, namely, presenting the odors and asking subjects to identify, from a list, what taste if any had been most frequently associated with them.

Experiment 1 provided no direct evidence of an associative account of the sweet enhancement effect observed by Frank and Byram (1988). However, any change in sweetness of the sucrose–flavor combination, postconditioning, for the flavor that had been paired with sucrose, may have been obscured by a ceiling effect. Recall that subjects rated the odors first, then the taste–flavor combinations in the pretest. The odors were rated less sweet and less sour than the taste–flavor combinations (sucrose alone was rated as about twice as sweet as the odors and citric acid alone as about three times as sour as the odors). The initial ratings for the odors provide a baseline for subsequent judgments of sweetness and sourness throughout the experiment (for an example of the longevity and nature of such context effects, see Vollmecke, 1987, and Stevenson & Prescott, 1994). Therefore, the high values recorded for the taste–flavor combinations on pretest may have worked against the appearance of any effect resulting from the pairings in the conditioning sessions of the experiment. To address this problem the order within the pretest was reversed in the second experiment, so that the taste–flavor combinations would be presented first, followed by the odors.

EXPERIMENT 2

Method

Subjects. Twenty-four University of Sydney first year undergraduates, none suffering from colds or other respiratory infections, took part in the experiment as part of their course requirements. No subject had participated in the first study. The experiment was again advertised as a "Flavor judgment experiment."

Stimuli. The same odor and taste stimuli were used in this experiment as described for Experiment 1.

Procedure. The principal change in method between this experiment and Experiment 1 was to reverse the order of the pretest, so that this time the taste–flavor combinations were rated first, followed by the odors. The only other procedural change occurred following the posttest. Subjects were presented with the first target odor using the same order of presentation as in the posttest. When they had smelled the odor, they were handed a multiple choice rating sheet and asked, "Which out of the following tastes, if any, can you recall being most frequently associated with this odor during this experiment?.'' Subjects were presented with five response options: No taste at all; Salty; Sweet; Sour; and Unsure. The position of the Salty, Sweet, and Sour response options was varied randomly between subjects, but the No taste at all and Unsure options always came first and last, respectively. Subjects then judged, on a separate sheet of paper, how certain they were of their response using the same scale as described in Experiment 1. The same procedure was then repeated for the second odor. Subjects were then fully debriefed.

Results

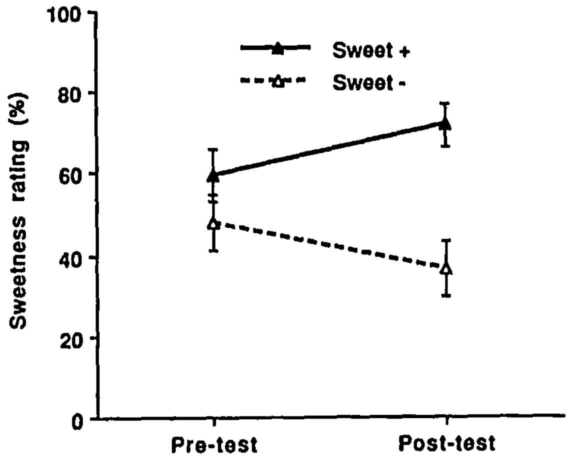
Two subjects failed to return for their third conditioning session and 1 for the posttest, leaving 21 subjects. Of these, following the criteria used in Experiment 1, 1 subject was eliminated from the analysis as she rated the citric acid stimulus on posttest as being considerably more sweet than sour. Of the 20 included in the analysis, 9 had been exposed to WC–sucrose and LY–citric acid and 11 to LY–sucrose and WC–citric acid. Of these 20, 15 were female and 5 male. Thirteen subjects completed the posttest on the day following the last conditioning session, while 7 subjects completed it between 2 and 7 days later. There was no significant difference in performance between these two subgroups of subjects.

Odors. As in Experiment 1, ratings of sweetness for the odor paired with sucrose increased significantly and for the odor paired with citric acid, sweetness decreased significantly. The overall difference between these changes was also significant, though somewhat smaller than in Experiment 1, in that the change corresponded to approximately one-quarter of the rating scale (see Table 4 and Fig. 2). Though LY and WC again differed in sweetness on the pretest (LY: mean

TABLE 4
Experiment 2: Changes in Sweetness and Sourness for the Target Odors and Flavors, Pre- to Posttest, Expressed as Mean Difference Scores

Difference score (Posttest minus pretest)	Odors		Flavors	
	Mean (*SD*)	$t(19)$	Mean (*SD*)	$t(19)$
(1) Sweetness difference for sweet–odor pairing	12.3 (29.1)	1.89*	7.4 (9.5)	3.47*
(2) Sweetness difference for sour–odor pairing	−11.4 (23.7)	2.16*	0.9 (15.9)	0.25
(3) Net change in sweetness (1) − (2)	23.7 (33.9)	3.13*	6.5 (17.9)	1.63**
(4) Sourness difference for sour–odor pairing	14.4 (31.6)	2.04*	6.7 (31.7)	0.95
(5) Sourness difference for sweet–odor pairing	−10.1 (28.4)	1.60**	11.8 (26.7)	1.98*
(6) Net change in sourness (4) − (5)	24.5 (44.6)	2.47*	−5.1 (28.3)	0.80

Note. All tests are one-tailed and significant where stated.
* $p < .05$; ** $p < .10$.



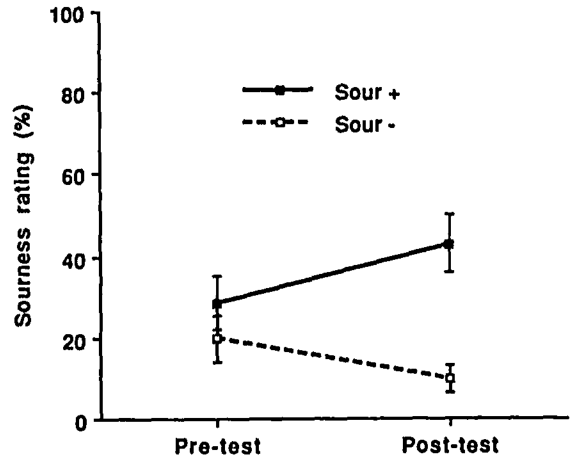


FIG. 2. (Top) Mean visual analog scale ratings on pretest and posttest of sweetness (0 = no sweetness), for the odor paired with sucrose (Sweet+) and for the odor paired with citric acid (Sweet−), in Experiment 2. (Bottom) Mean visual analog scale ratings on pretest and posttest of sourness (0 = no sourness), for the odor paired with citric acid (Sour+) and for the odor paired with sucrose (Sour−), in Experiment 2. Means are shown with standard errors.

72.1; WC: mean 35.1; $t(37) = 5.04$), the degree of change in sweetness for each odor was not significantly different. The pattern of results for the odor paired with citric acid obtained in Experiment 1 was also observed, in that this significantly increased in perceived sourness. Again, there was no change in sourness for the odor paired with sucrose. The overall change in sourness was approximately of the same magnitude as observed previously, in that the change represented about one-quarter of the rating scale (see Fig. 2). In this experiment subjects judged the WC odor to be more sour than LY on pretest (LY: mean 10.7; WC: mean 37.6; $t(29) = 3.56$). However, the degree of change in sourness did not differ between odors. A significant correlation was again observed between changes in sweetness ratings for the odor paired with sucrose with changes in sourness ratings for the odor paired with citric acid (Pearson's r = .43, one-tailed).

Ratings of overall intensity increased for the odor paired with sucrose (mean difference = 5.4; t = 1.93, one-tailed), but not for the odor paired with citric acid (mean difference = −0.9). In Experiment 2, there was no significant difference between ratings of overall intensity for the odors on pretest (LY: mean 63.3; WC: mean 56.7).

There was no evidence in this experiment of any positive or negative liking change either for the odor paired with sucrose (mean difference = 4.2) or for the odor paired with citric acid (mean difference = 4.2). The odors did, however, differ in their initial ratings of pleasantness (LY: mean 68.6; WC: mean 34.1 $t(32)$ = 6.91), but changes in liking did not differ between odors.

Familiarity ratings in this experiment were more variable than in Experiment 1, perhaps because the tastes and flavors preceded the judgments of odor familiarity on pretest. With WC odor, subjects were slightly unsure whether they had smelled anything similar to it before, but were certain they had at posttest (Wilcoxon signed rank test, $T(10)$ = 9, one-tailed). On the second familiarity question, subjects were unsure whether they had smelled WC before during pretest, though they were more certain that they had smelled it before at posttest ($T(10)$ = 10, one-tailed). For LY, subjects reported that they had smelled odors similar to it both pre- and posttest. On the second question, subjects were still unsure at posttest whether they had smelled exactly that odor before. There were no significant changes for either of these two questions, pre- to posttest. Comparing familiarity between odors at pretest revealed that subjects were more familiar with odors similar to LY than WC ($T(13)$ = 16.5). However, for both odors, subjects were unsure when asked whether they had smelled that particular odor before.

Ratios of variance were calculated again for sweetness and liking ratings for the same sets of data as described in Experiment 1. As before, sweetness rating variances were always larger than the comparable liking variances, though the magnitude of the difference was smaller, with two ratios of around 2 and one of 1.2.

Flavors and tastes. The analysis of sweetness and sourness changes, pre- to posttest, for the taste–flavor data, revealed a significant increase in subjects' perception of sweetness for the flavor–sucrose solution where that flavor had been previously paired with sucrose (see Table 4). However, there was also a significant increase in sourness for the flavor–sucrose solution, which makes this former result more difficult to interpret. The more crucial overall difference in scores between sweetness ratings for the sucrose and citric acid paired flavors revealed a nonsignificant trend for increased sweetness. For sourness, no such change occurred.

Manipulating the order of the smelling and tasting tasks on pretest did appear to impact on sweetness ratings as expected. An independent t test of sweetness ratings of the sucrose solution in Experiment 1 against those in this experiment revealed a significant decrease in ratings of about 8% (mean in Experiment 1, 89.5 and in Experiment 2, 81.9; $t(33) = 2.53$, one-tailed). However, there was no significant change in sourness ratings of the citric acid solution between experiments.

The overall intensity data revealed a significant increase in intensity for the flavor–sucrose stimulus, where that flavor had previously been paired with sucrose (mean difference = 8.3; $t = 2.30$) and for a nonsignificant trend for increased intensity for the flavor–citric acid stimulus where that flavor had been previously paired with citric acid (mean difference = 8.3; $t = 2.05$, $p < .06$). No significant changes were observed for the liking data.

Debriefing. Fifteen subjects of 20 correctly identified the odor that had been paired with sucrose and 10, the odor that had been paired with citric acid (see Table 5). It was of considerable interest to determine whether the changes in perceived sweetness or sourness of an odor were different for subjects who revealed some knowledge of the contingencies on this test than changes in subjects who did not reveal such knowledge. The odor–sucrose and citric acid change data (Table 4, odor items (3) and (6), respectively) were reanalyzed, with subjects split into groups depending on either correct or incorrect recognition of the odor/flavor–taste pairings. There was no significant difference between groups for either sweet ($t = 0.54$) or sour ($t = 0.71$) odor change data. One sample t tests were then conducted on these data for the nonaware subgroups (Table 4, odor items (3) and (6)). For the odor paired with sucrose there was no significant change in odor sweetness, though the t value was large given the small sample size (mean difference = 51.8, $t(4) = 1.41$). The odor paired with citric acid significantly increased in perceived sourness in the nonaware subjects (mean difference = 48.6, $t(9) = 2.11$, one-tailed).

TABLE 5
Experiment 2: Subject Responses on the Contingency Awareness Test

Odor, paired with, correct/incorrect identification	Very or fairly certain	Very or fairly uncertain	Total
WC, Sour, Correct	6	2	8/11
WC, Sour, Incorrect	0	3	3/11[a]
LY, Sour, Correct	1	1	2/9
LY, Sour, Incorrect	6	1	7/9[b]
WC, Sweet, Correct	4	0	4/9
WC, Sweet, Incorrect	4	1	5/9[c]
LY, Sweet, Correct	11	0	11/11
LY, Sweet, Incorrect	0	0	0/11

[a] One subject replied "No taste at all"; one, "Salty"; one "Unsure."
[b] Six subjects replied, "Sweet"; one "Unsure."
[c] Three subjects replied, "Sour"; one, "No taste at all"; one, "Unsure."

Although these questions were intended to determine which subjects were aware of the contingencies, this may not have been completely successful. The pattern of errors suggested that the number of subjects who claimed to "know" which odor had been paired with which taste may have been inflated, as some subjects may have been making their choice on the basis of the most salient attribute of the odor. This is suggested by the fact that LY had been perceived as being paired with sweet by six subjects for whom it had in fact been paired with sour. In contrast, no subject indicated that WC had been paired with sweet when in fact it had been paired with sour. This asymmetry may have resulted from LY being perceived as sweeter than WC from the outset, as indicated by the pretests in both experiments. Debriefing again failed to reveal any awareness of the experimental hypotheses or any prior knowledge about the true nature of the experiment.

Discussion

Experiment 2 replicated the main finding of Experiment 1, namely, that as a result of experiencing an odor as a flavor mixed with sucrose or citric acid during the conditioning sessions, it is perceived as possessing more of the associated taste attribute on posttest. This experiment also provided some indication of a sweetness-enhancement effect, in that the sucrose-paired flavor was rated sweeter when tasted with sucrose posttest than in pretest. With respect to subjects' awareness of contingencies, it appears that this was not a prerequisite for a change in odor perception. However, as discussed above, this finding must be considered preliminary and additionally so because of the presence of the posttest taste–flavor combinations immediately prior to the contingency awareness test, which might also have confused subjects (i.e., retroactive interference).

The results of Experiment 2 may have some bearing on the taste enhancement effect observed by Frank and Byram (1988) and Frank, Ducheny, and Mize (1989). As noted earlier, they suggested that the ability of strawberry odor to increase the sweetness of sucrose containing stimuli might result from the frequency of occurrence of "strawberry" and "sweet" outside of the laboratory. They specifically suggested that associative mechanisms might underlie this observation. The results are supportive of Frank's position in as much as frequent pairings of a flavor and sucrose do appear to result in sweetness enhancement. However, this result must be considered tentative, as the finding that sourness ratings also increase for the flavor–sucrose pairing might indicate the operation of some nonassociative effect.

The changes in odor perception seem to represent a robust phenomenon. However, the possible effect of mere exposure to the odors alone could not be ascertained in Experiments 1 and 2. Although each odor in the experiments described above acted as a control for the other, it is conceivable, for example, that changes in sweetness might be attributed to exposure, while changes in sourness might be an associative phenomenon, or vice versa. This issue is particularly relevant to human evaluative conditioning, where it can be very difficult to control adequately for subtle effects of stimulus exposure as exemplified in the critique by Shanks and Dickinson (1990) of the methods employed by Levey and Martin (1975) and Martin and Levey (1978). Therefore, a further experiment was conducted to evaluate the effect of exposure alone on the perception of the target odors (LY and WC).

EXPERIMENT 3

Method

Subjects and procedure. Twelve CSIRO staff volunteered to participate, with 8 successfully completing the experiment (5 females, 3 males). No subject had any experience with these odors or was unwell at the time of the study. The procedure was exactly the same as that used in Experiment 1, except that the odors were never mixed with either sucrose or citric acid, nor were these tastes present during any phase of the experiment. During pretest and posttest, odors were smelled and then tasted, twice each in a solution of distilled water. On ''conditioning'' sessions, the same masking set was used, but the target odors were just mixed with distilled water. As before, every session was separated by at least 24 h.

Results and Discussion

No changes in sweetness or sourness ratings, pre- to posttest, as a result of exposure to the WC or LY flavor during the conditioning sessions were observed (all t tests were one-tailed for all comparisons where some prior expectation of direction could be made). However, there was a significant increase in overall intensity for the LY odor (mean difference = 22.3; $t(7) = 3.56$, one-tailed) and a nonsignificant trend for the same effect in the WC odor (mean difference = 14.4; $t(7) = 1.86$, $p < .07$, one-tailed). Liking changes for the WC and LY were nonsignificant, though both revealed a trend for an increase in liking of about 6% of the scale ($t = 0.88$ and 1.60, respectively).

The taste flavor data revealed no changes in perception of sweetness or sourness, though a significant increase in overall intensity was observed for LY flavor (mean difference = 15.5; $t(7) = 2.70$, one-tailed), though no concurrent change was observed for the WC flavor. There were no significant changes in liking ratings. The subject debriefing questionnaire revealed subjects had no apparent awareness of the purpose of the study.

Though Experiment 3 was conducted on a small nonstudent sample, the results offer no direct challenge to our main findings. They do, however, suggest that the changes in overall intensity which were recorded in both Experiments 1 and 2 may have occurred regardless of the pairings with sucrose or citric acid.

GENERAL DISCUSSION

Two main points arise from these experiments. First, odors experienced as flavors paired with either sucrose or citric acid can acquire properties that are perceived as being similar to or the same as the taste with which they had been paired. Second, there was no strong evidence that awareness of the contingencies was necessary for observation of perceptual change toward the target odors.

Both theoretical prediction (Rozin & Zellner, 1985; Rozin & Vollmecke, 1986) and previous research on humans (Zellner *et al.*, 1983) would suggest that the procedures used in these experiments, principally for the flavor paired with sucrose, would result in a positive increase in subjects' hedonic response toward that flavor. In the experiments reported here we observed no evidence to support this prediction, even though the larger variances described here for odor sweetness ratings might have been expected to make it more difficult to detect a change in odor taste attributes rather than a change in liking. It may also be noted that Rozin (personal communication) has had little success in repeating Zellner *et al.*'s (1983) results, though admittedly under somewhat modified circumstances and as discussed earlier, in the only other comparable published study (Baeyens *et al.*, 1990a) no positive hedonic shift was observed. Our findings then would suggest that even when experimenters detect little or no hedonic change in this type of study, subjects may still be affected by the relationship of the odor or flavor to its paired taste, but as expressed by changes in its taste properties.

The extent to which our selection of odors assisted in demonstrating the observed effects is of interest. Both odors were rated initially, by all groups in all experiments, as generally possessing attributes of sourness and sweetness. Though the sourness ratings may have arisen as a result of subjects' reluctance to use the extreme end of the rating scales, the saltiness data from the odor selection experiment would suggest that this was unlikely, mainly as its mean ratings were generally less than 3% of the scale length. If this value is used as a representative rating for a "nonexistent" attribute, then the mean ratings for sourness recorded for the odors in Experiments 1 and 2 were always well above this. The process of pairing may then have accentuated these extant attributes of sweetness and sourness. This raises the question of whether such effects could have been shown for odors not initially possessing that quality. Though our data cannot address this question, it may well be a useful line of inquiry as it may offer insight into the form of knowledge that is acquired during the pairings.

We suggest that associative learning is responsible for the changes in odor perception observed in the experiments reported here, but some caution may be required before firmly concluding that this is the case. Even though considerable care was taken by the use of a highly standardized procedure to prevent any influence by the experimenter, the possibility remains that some form of inadvertent cueing may have taken place, as the experimenter was not blind to the condition of the subject. However, this reservation also applies to many previously reported studies of human flavor conditioning and to evaluative conditioning in general. A further alternative explanation might be that as the only two taste quality scales present during the experiment were sweet and sour, this might lead subjects to believe that a response concordant to the taste that the flavor/odor had been paired with previously was what the experimenter expected. The strongest rebuttal of this type of demand-based explanation is the observation that responses did not significantly differ between aware and nonaware subjects during the second experiment, a result that would argue against this interpretation.

Assuming that these reservations can be discounted, at least until further testing is carried out, and that the present results reflect the outcome of associative learning, the question arises as to the nature of such learned effects. One possibility is that subjects explicitly remember the taste when the appropriate odour is presented. Another is that the odor activates a sensory representation of the taste. The latter is suggested by research on "learned synesthesia" (e.g., Howells, 1944) with human subjects and more recently by results obtained by Holland (1990) with rats, which indicate that auditory stimuli can acquire flavor-like properties following pairing of such a stimulus with a specific flavor. Although the present experiments were not designed to test between these alternatives, the data obtained in the "awareness" tests clearly bear upon this issue.

The nature of the relationship between changes in a subject's performance resulting from a contingency between two events and subject's "awareness," in the sense of consciously perceiving and subsequently reporting that contingency, is an issue with a long history in the study of human learning. Many early reports of "conditioning without awareness" were based on completely open-ended questioning of subjects following a conditioning session, of the kind we chose to employ in Experiment 1 as an initial approach to this question (see Boakes, 1989; Brewer, 1974). This can provide a marked underestimate of subjects' explicit knowledge of the contingencies, as demonstrated most systematically in a series of human shock-based conditioning experiments using skin conductance as the dependent variable (e.g., Dawson & Schell, 1987). With such procedures it is found that a multiple choice ("recognition test"), of the kind used here in Experiment 2, can reveal far more knowledge of the contingencies embedded in the masking task than can an open ("recall") test of awareness (Dawson & Reardon, 1973). Furthermore, with such a conditioning procedure a marked difference is found between the performance of "aware" and "unaware" subjects. Typically, no sign of conditioning is found in unaware subjects, so that to date there is no firm evidence for conditioning without awareness from this kind of preparation (Dawson & Schell, 1987).

A similar conclusion is emerging from the more recent literature on implicit learning where studies have examined, for example, artificial grammar learning (e.g., Reber & Allen, 1978) or changes in reaction times resulting from contingent relations between stimuli embedded in some serial reaction time task (e.g., Nissen & Bullemer, 1987). Two conclusions emerging from such results are again that, first, there is a marked difference in the performance of aware and unaware subjects and, second, that, when care is taken to uncover subjects' explicit knowledge of the embedded contingencies, no learning has been found in subjects who revealed no such knowledge of the contingencies (e.g., Perruchet, in press; Shanks & St. John, 1994).

The claim has been made that the strongest evidence for learning without awareness may be found using procedures that employ evaluative or hedonic conditioning (e.g., Martin & Levey, 1987; Baeyens, Eelen, & van den Burgh, 1990b) or that employ stimuli such as flavors which are difficult to label consistently (e.g., Baeyens *et al.* 1990a). The present results add support to the latter claim, even though they suggest that hedonic changes are not the most productive measure for detecting such learning. The data providing strongest support was the failure to find any difference in the posttest rating of odors for taste qualities between subjects in Experiment 2 who made correct identifications in the final multiple choice test and those who did not. This negative finding is in marked contrast to the results from skin conductance and implicit learning studies referred to above.

This multiple choice test was clearly not a perfect indicator of "awareness" for reasons discussed earlier. Briefly, on the one hand, it may have yielded an overestimate in that many subjects may have correctly identified LY as having been paired with sucrose simply because its most salient taste attribute was "sweetness" and not because they had encoded the pairing. On the other hand, the immediately preceding taste–flavor tests may have generated some retroactive interference which produced errors on the multiple choice test. Informal evidence comes from the universal surprise expressed by subjects in both experiments when the nature of the conditioning sessions was explained during the final debriefing and from the suggestion in some cases that, where a subject had confidently and correctly identified that a particular odor had been frequently paired with a sweet or sour solution, this was a product of hindsight rather than something which had been noticed at the time.

Finally, whatever its bearing on the question of learning without awareness, the main conclusion to be drawn from this set of experiments is that associative learning plays a major role in the acquisition of taste-like properties by odors.

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