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Resistance to Extinction of Conditioned Odor Perceptions: Evaluative Conditioning Is Not Unique

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A tasteless odor will smell sweeter after being sampled by mouth with sucrose and will smell sourer after being sampled with citric acid. This *tasty-smell* effect was found in experiments that compared odor–taste and color–taste pairings. Using odors and colors with minimal taste (Experiment 1), the authors found that repeated experience of odor–taste mixtures produced conditioned changes in odor qualities that were unaffected by intermixed color–taste trials (Experiment 2). An extinction procedure, consisting of postconditioning presentations of the odor in water, had no detectable effect on the changed perception of an odor (Experiments 3 and 4). In contrast, this procedure altered judgments about the expected taste of colored solutions. Evaluative conditioning (conditioned changes in liking) is claimed to be resistant to extinction. However, these results suggest that resistance to extinction in odors is related to the way they are encoded rather than to their hedonic properties.

When people experience something they like or dislike at the same time as something to which they are indifferent, their hedonic evaluation of the indifferent item can change in the affective direction of the liked or disliked event (Martin & Levey, 1978). For example, Zellner, Rozin, Aron, and Kulish (1983) found that initially adding sucrose to particular teas resulted in greater liking for these teas when presented without sucrose than for teas never mixed with sucrose. It has been claimed that this kind of learning, termed *evaluative conditioning* by Martin and Levey (1994), possesses unusual properties. Because this type of conditioning has important implications for the treatment of phobias (e.g., Baeyens, Eelen, van den Bergh, & Crombez, 1989) and for increasing the effectiveness of advertising (e.g., Allen & Janiszewski, 1989; Gorn, 1982), determining if evaluative conditioning has special properties is of considerable practical, as well as theoretical, interest.

Recent research on evaluative conditioning has relied mainly on two methods. One method is to pair neutral visual stimuli such as faces or pictures of statues with stimuli from the same category, which are affectively positive or negative (e.g., Baeyens, Hermans, & Eelen, 1993; Hammerl & Grabitz, 1996). The other method is to pair odors with liked or disliked tastes (e.g., Baeyens, Crombez, Hendrickx, & Eelen, 1995). Evaluative conditioning is demonstrated by an increase in liking for the neutral stimuli paired with positive events or a decrease in liking for those paired with negative events. Such experiments have generated three major claims. The first is that evaluative conditioning can occur without awareness of the experimental contingencies, in that measures of awareness fail to correlate with the degree of evaluative conditioning (e.g., Baeyens, Crombez, van den Bergh, & Eelen, 1988; Baeyens, Eelen, van den Bergh, & Crombez, 1990). This claim contrasts with the general finding that learning is highly correlated with awareness in other forms of human conditioning (e.g., Boakes, 1989; Brewer, 1974; Dawson & Schell, 1987) and in various implicit learning procedures (e.g., Shanks, Green, & Kolodny, 1994; Shanks & St. John, 1994). The second claim is that evaluative conditioning does not depend on a contingent relationship between events but on a contiguous relationship between them in that varying the predictive relationship between stimuli has no effect on conditioning (Baeyens et al., 1993). This claim contrasts with the general finding that a contingent relationship between events is a necessary condition for both human (e.g., Shanks, 1985) and animal learning (e.g., Rescorla, 1968). The third claim is that a conditioned change in hedonic value is resistant to extinction. Researchers have explored resistance to extinction in two separate studies (Baeyens et al., 1988; Baeyens et al., 1989). In neither study was there any evidence of a change in participants' evaluative ratings following presentation of the conditioned stimuli when their associated negative or positive images (unconditioned stimuli) were absent. This claim contrasts with the hitherto universal finding from other human conditioning studies that extinction typically occurs within a few trials (e.g., Dawson & Schell, 1987).

Some ambiguity can occur in the terminology used to describe the second method for studying evaluative conditioning, that involving odors and tastes (e.g., Baeyens et al., 1990; Baeyens et al., 1995). Consequently, the following

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definitions are used here. *Taste* will refer to the sensations of sweet, sour, salty, and bitter, which are detected solely by the tongue. Odor perception is not so easily defined because, although detection relies on only one set of receptors (the olfactory mucosa), odors reach those receptors by two separate routes (Pierce & Halpern, 1996). The first route is by smelling through the nostrils, referred to here as *orthonasal perception* or *sniffing*. The second route is used whenever stimuli are placed in the mouth and the odor ascends through the posterior nares of the nasopharynx. This is referred to here as *retronasal perception* and results from eating, drinking, or other forms of oral ingestion involving odors (Pierce & Halpern, 1996).

In presenting neutral odors with liked and disliked tastes, evaluative conditioning is said to have taken place if the hedonic value of an originally neutral odor changes in the appropriate direction. In experiments of this kind, Baeyens et al. (1990; 1995) have found further support for two of the claims made on the basis of experiments using visual stimuli. The first claim is that changes in liking for odors appear to occur without awareness. This was most effectively demonstrated in an experiment in which participants were exposed to trials containing both color–taste and odor–taste solutions. Changes in liking for the odors appeared to occur independently of awareness, as measured by a postexperiment questionnaire. For colors, no changes in liking occurred even though participants were aware of the relationships between colors and tastes (Baeyens et al., 1990). A further experiment using odors supported the claim that such conditioning is resistant to extinction. In this case, following conditioning of an odor, four presentations of the odor in water produced no detectable change in evaluative judgments of the odor (Baeyens et al., 1995).

Although there has been considerable criticism of the research on evaluative conditioning that has used visual stimuli (e.g., Davey, 1994a, 1994b; Fields & Davey, 1997; Shanks & Dickinson, 1990), conditioning using odors is not currently under question. However, results from a methodologically similar series of experiments (Stevenson, Prescott, & Boakes, 1995) suggest that the unique properties attributed to evaluative conditioning may not be unique after all. In these studies the main focus has been on changes in the perceptual properties of odors rather than on changes in their hedonic properties.

In a typical study (Stevenson et al., 1995), an odor sniffed and rated on several sensory dimensions (sweetness, sourness, etc.) at the beginning of an experiment will subsequently smell sweeter if experienced retronasally in a mixture with sucrose, and it will smell more sour if experienced in a mixture with citric acid. These changes are associative in that when a sucrose-paired odor is contrasted with a water-paired control, no change is observed in sweetness for the water-paired odor (Stevenson, Boakes, & Prescott, 1998). Apart from the procedural similarities between evaluative and perceptual odor conditioning, there are two further parallels. The first is that the acquisition of perceptual properties appears to occur with a minimum level of conscious awareness (Stevenson et al., 1998). Like Baeyens et al. (1990), we have not been able to detect any relationship between contingency awareness and learning. The second similarity is in the form of encoding of the odor–taste mixture appearing to result from the conditioning procedure. In both cases, this has been described as *fused* or *holistic* (Martin & Levey, 1994; Stevenson et al., 1998).

If both forms of conditioning owe their similarities to the nature of odor–taste learning, then it is very likely that perceptual conditioning will behave like odor evaluative conditioning during extinction. An effective test of whether perceptual odor conditioning is resistant to extinction requires comparison with a form of learning that is susceptible to extinction. Such a comparison was not included by Baeyens et al. (1995) in their single test of odor extinction. An appropriate test is that used by Baeyens et al. (1990) to study awareness in odor conditioning, in which odor–taste and color–taste learning were compared. Because color–taste learning is presumed to be an example of explicit learning (Baeyens et al., 1990), then it may, as in other human learning studies, show evidence of extinction within 5 to 10 trials (e.g., Schell, Dawson, & Marinkovic, 1991).

Experiment 1a

This experiment assessed the perceptual properties of the stimuli to be used in Experiments 2 and 3, whereas Experiment 1b consisted of equivalent tests for additional stimuli used only in Experiment 4. The aim was to assess whether perception of the odors was based on stimulation of olfactory receptors as opposed to taste receptors. This was determined by preventing the odor from reaching the olfactory receptors by pinching participants' noses shut with a clip. This method is highly effective at resolving the olfactory and taste components of an oral mixture (Lawless, 1996). Ratings of the odors, presented as solutions in water and sampled by mouth, were obtained in the presence and absence of a nose clip. Thus, if the nose clip reduced ratings of the sweetness of an odor to a level indistinguishable from that of water, one could conclude that such ratings were based on olfactory stimulation alone. On the other hand, if the nose clip failed to affect the ratings, this would suggest that perception is based on stimulation of taste receptors alone. It was also important to check that the additives used to produce color possessed no taste or odor properties.

To maintain consistency with other studies in this series (Stevenson et al., 1995; 1998), we used essentially the same set of rating scales. The only difference was the addition of *bitterness* and *saltiness* ratings to the *sweetness, sourness, overall intensity,* and *liking ratings* used in the main experiments reported later. These extra ratings were included so that the four most important taste qualities (McLaughlin & Margolskee, 1994) were all represented.

Method

Participants

As in all experiments reported in this article, the participants were first-year undergraduates, none suffering from colds or other respiratory infections, who took part to fulfill course requirements. Also, for all experiments reported here, the study was advertised as a "Flavor judgment experiment," no participant had previously taken part in a related experiment, and participants were tested in groups of 1 to 4. There were 9 such participants in this experiment.

Stimuli

Selection of odor stimuli was based on previously reported work (Stevenson et al., 1995). The commercial-grade food flavorants used were lychee (0.30g/L in water; Quest), water chestnut (0.20g/L in water; Quest), and pear (0.33g/L in water; Quest). The taste stimuli were sweet, 4.3×10^{-1} mol (15% w/v) sucrose; sour, 7.5×10^{-3} mol (0.16% w/v) citric acid; salty, 8.6×10^{-2} mol (0.5% w/v) sodium chloride; and bitter, 5.4×10^{-5} mol (0.005% w/v) quinine sulfate monohydrate, all in water. Colorants were green (0.25g/L; Corella), red (0.5g/L; Corella), and blue (0.125g/L; Corella), all in water. All stimuli were presented as 10-ml samples in 22-ml transparent plastic cups, filled just prior to a session. Solutions containing sucrose were refrigerated. All stimuli were presented at room temperature in an air-conditioned room.

Procedure

The experiment involved tasting solutions of odors, colors, tastes, and plain water and rating their attributes. This procedure was conducted twice for each participant on separate days. On one day, the participant wore a nose clip to prevent retronasal and orthonasal olfaction. This clip was not worn on the other day. Whether the participant wore the nose clip on the first or the second day was determined by order of arrival at the experiment.

Participants were first given written instructions that described the sampling procedure and how to use the rating scales. The participants were to pour each sample into the mouth, gently roll it around, and then expectorate it. For the initial four training solutions—saline, citric acid, sucrose, and quinine—the experimenter named the tastant. Participants then ate a bread cube and proceeded to taste the next solution. Following the four training samples, the test phase began. Participants assigned to wear nose clips put them on. Each of 30 solutions was sampled and rated on the following attributes: sweetness, bitterness, sourness, saltiness, overall intensity, and liking. Scales were 15.3-cm lines with the following anchors: *none* and *extremely strong* for intensity ratings; and *dislike extremely*, *like extremely*, and a central marker, *indifference*, for the liking scale. Ratings were always presented in the aforementioned order. Test solutions were presented in a different, randomized order for each participant and consisted of 10 solutions of plain water; 2 solutions each of red, blue, and green color in water; 2 solutions each of lychee, water chestnut, and pear in water; and 2 solutions each of salt, citric acid, sucrose, and quinine in water.

Analysis

Mean ratings for each of the solutions, converted to a 100-point scale as in all subsequent experiments, were calculated separately for the clip and no-clip conditions. The first analysis was to determine whether the odors had any taste properties, and the second was to determine whether the colors had any smell or taste. Nonparametric tests (Friedman) were used because of substantial departures from normality. For the same reason, medians were used in preference to means. All reported values are significant at the 5% level unless otherwise stated. Ratings of the tastants alone are not reported because they did not reveal anything of interest.

Results

As may be seen in the top left panel of Figure 1, sourness ratings were consistently very low. No effect of the nose clip was detected for this measure. Sweetness ratings, shown in the mid-left panel, were higher for the odor stimuli than for water alone, but only when the nose clip was absent, $F_r(3) = 10.1$. Liking ratings, shown in the bottom panel, were unaffected by the nose clip. Odors were appropriately rated as more intense than water, $F_r(3) = 9.5$, in the absence of the nose clip, but no differences were detected when it was worn. There were no significant differences between colors and water on any rating scale regardless of whether the nose clip was present or absent.

Discussion

Ratings of all three odors were indistinguishable from water when the nose clip was worn, implying that perception of these odors was based entirely on olfactory stimulation. This experiment provides a good example of how participants can confuse taste and olfactory stimuli in that they regarded the sweetness of these odors as a taste quality even after training with each taste type. There was no indication that the colorants possessed any taste or odor properties at the concentration used here.

Experiment 1b

Method

This experiment used the same method as in Experiment 1a to investigate whether a further odor and color used only in Experiment 4 had any taste and, in the case of the color, any smell. There were 14 participants. The procedure was identical except for the following modifications. Only one color (yellow; 0.25g/L; Corella) and one odor (blueberry; 0.05g/L in water; Dragoco) were tested, the number of water-only trials was reduced to six in each condition, and the clip-present and clip-absent conditions were both completed in the same session. Wilcoxon tests were used in this analysis.

Results and Discussion

Sourness ratings for blueberry and water only (top right panel in Figure 1) were unaffected by the clip. Sweetness ratings for blueberry (middle right panel in Figure 1) were significantly greater than those for water, both when a clip was worn ($Z = 2.64$) and when absent ($Z = 3.18$). Liking ratings (bottom right panel in Figure 1) for blueberry and water did not differ when the clip was present, but when it was absent, blueberry was judged as more pleasant than water ($Z = 3.70$). Blueberry and water did not differ on any other taste scale. Intensity ratings for blueberry and water did not differ when the nose clip was worn, but when it was absent, blueberry was perceived as more intense than water ($Z = 1.98$). There were no differences between yellow and water on any measure whether the clip was present or absent.

Apart from a significantly higher median sweetness rating for blueberry in the nose-clip condition, the results were

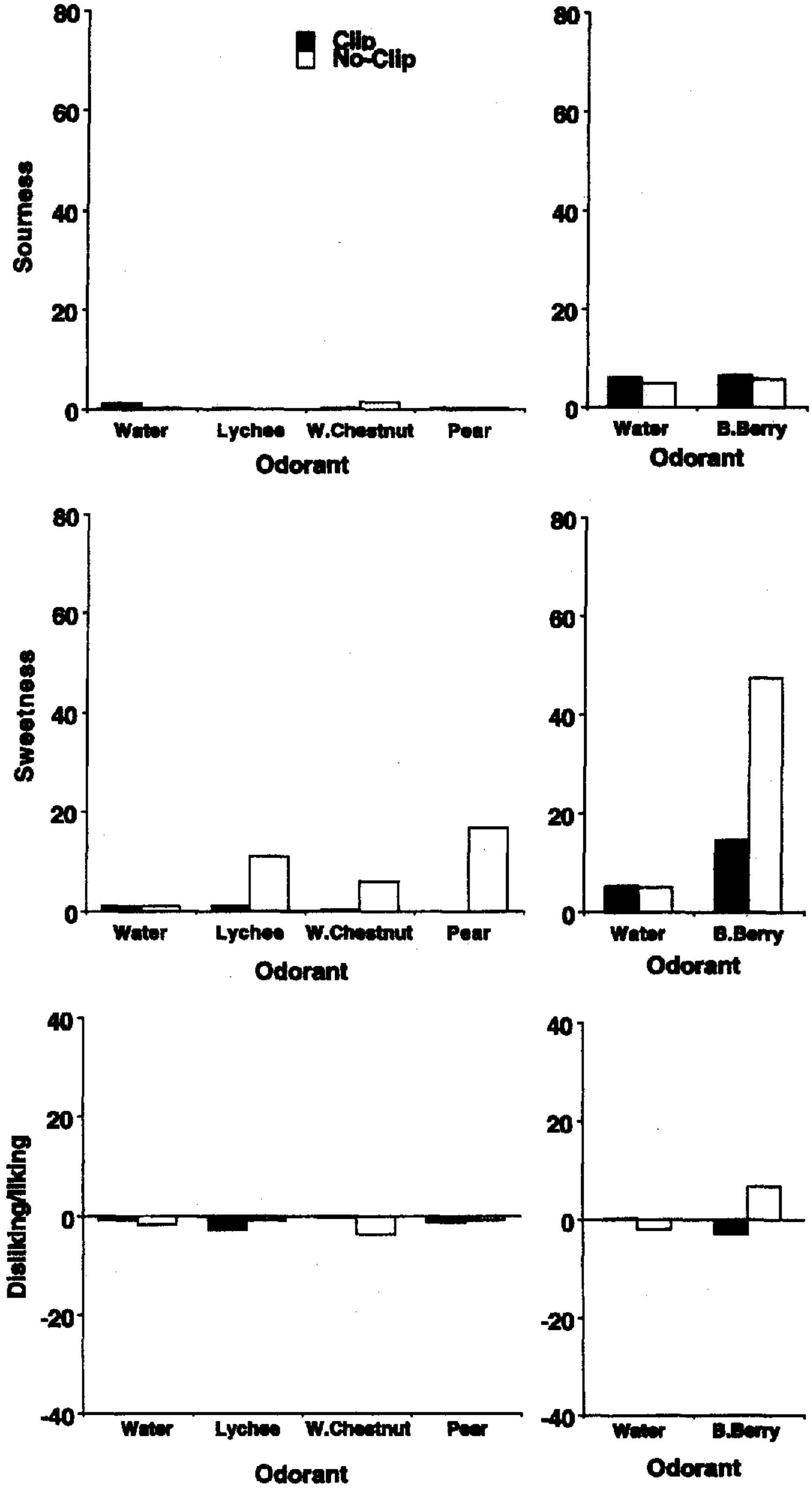

Figure 1. Experiments 1a (left panels) and 1b (right panels). Median ratings on 100-point scales for odors in water and water alone, sampled by mouth with or without nose clip. Top row: sourness ratings. Center row: sweetness ratings. Bottom row: liking ratings. W. Chestnut refers to water chestnut odor, and B. Berry refers to blueberry odor.

similar to those from Experiment 1a; namely that the odor and color have little taste, and the color has no smell.

Experiment 2

This experiment had two aims. The first was to investigate whether color conditioning would influence the acquisition of odor–taste associations, because Baeyens et al. (1990; 1995) found some higher order interactions involving color. This test was necessary because the extinction experiments reported later require an assumption of independence between odor and color learning. The second aim was to test an acquisition procedure involving just two sessions. In previous experiments, participants attended five individual sessions over several days, and a large number of dummy trials were used to mask the odor–taste contingencies (Stevenson et al., 1995; 1998). This allowed us to test whether odor–taste learning obtained under these conditions would be of a similar magnitude to that which was observed before. If so, this would allow us to make a substantial procedural simplification in the later, more complicated, extinction experiments.

In outline, the method was as follows. A sniffing pretest was given at the start of the first session and repeated at the end of the second. The sessions were separated by at least 24 hr. In between these pre- and posttests, conditioning was given in the form of repeated presentations of four kinds of trials, in which participants sampled and then expectorated a solution. In one type of trial, one odor was added to a sucrose solution and in another a second odor was added to a citric acid solution. The remaining two types consisted of colored solutions of sucrose and of citric acid, with no added odors. This procedure was expected to generate the *tasty-smell* effect, i.e., from pre- to posttest the sucrose-paired odor would smell sweeter, whereas the citric-paired odor would smell more sour. No direct assessment of color–taste learning was made in this experiment; however, because it was intended to test if such learning might influence odor judgments, participants sniffed colored as well as colorless odor samples in both pre- and posttests. During the conditioning phase, the only task that participants were asked to perform was to judge whether the current sample tasted the same or different than the preceding sample. This was to ensure that they attended to stimuli and to provide consistency with the description of the experiment as being about *flavor judgments.*

Method

Participants

Twenty-seven participants completed this experiment.

Stimuli

The odors were lychee (0.12g/L in water) and water chestnut (0.08g/L in water). The same concentrations were used when the odors were mixed with taste stimuli and presented orally. The taste stimuli were sweet, 4.5×10^{-1} mol (15.4% w/v) sucrose, and sour, 7.5×10^{-3} mol (0.16% w/v) citric acid in water. Colorants were green (0.25g/L; Corella) and red (0.5g/L; Corella). Odors were presented in transparent plastic polypropylene 250-ml wash bottles each containing 50 ml of odorant in solution. They were replenished on the morning preceding a participant's first session. Stimulus presentation was the same as for Experiments 1a and b.

Procedure

The first session began with a pretest that consisted of sniffing and rating eight samples. These samples consisted of the two odors dissolved in two bottles of uncolored water; in two bottles of red water, in two bottles of green water, and in a further two bottles, one containing only sucrose and the other containing only citric acid solution. The color of the fluids in the odor bottles could be clearly seen. Participants were given written instructions describing the pretest and how to use the rating scales and were then briefed on how to sample the odors. This involved placing the 3-cm plastic spout of the bottle (opening diameter 0.4 cm) approximately 4 cm below the nose and vigorously squeezing the plastic bottle while sniffing. Participants were told to take as long as they wanted to smell the odor because they would not be able to smell it again once they were handed the rating sheet. Extra sniffing beyond the first sniff provides the participant with little further information, merely confirmation (Laing, 1983). Participants then smelled the series of samples in a sequence determined by Williams square (Edwards, 1968) so that every sample had an equal probability of being followed by any other sample.

After smelling the odor the participant completed the first rating sheet. This contained four 15.3-cm visual analogue scales (VAS) in the following order: *liking/disliking, overall intensity, sourness,* and *sweetness* (the same anchors as in Experiment 1). Participants were then asked "Before today, had you EVER smelt a SIMILAR odor to this before?" Available responses were yes, unsure, and no. They were then asked "Before today, had you EVER smelt THIS odor before?" Available responses were yes, unsure, and no. On completion of the rating sheet, participants followed the same procedure for all the subsequent odors.

Participants were not given specific definitions of what *sweet* or *sour* might mean in the context of judging odors rather than tastes. However, if a participant did ask they were given the following definitions: For sweetness, "a sweet smell similar to that of freshly baked cakes"; and for sourness, "a sour smell similar to that of vinegar." Participants had little difficulty in applying sweet or sour ratings to the odors.

Following the pretest, participants completed the first set of conditioning trials. Participants were given instructions detailing the task and were asked to "Try to work out what a solution will taste like BEFORE you taste it! Do this in your head and don't mention your 'predictions' to the experimenter." Each conditioning period contained five blocks of four trials. Participants were assigned by order of arrival at the first session to one of the four counterbalanced training conditions, (e.g., lychee–sucrose, red–sucrose, water chestnut–citric, and green–citric). Each four-trial block contained one trial of Odor 1 in sucrose, one trial of Odor 2 in citric acid, one trial of Color 1 in sucrose, and one trial of Color 2 in citric acid. Order of presentation within a block was random.

On each trial, participants poured all of a solution into their mouth, sampled it, and expectorated. They were then asked to indicate whether the solution they had just tasted was the same or different from the preceding solution. (No rating was made following the first solution.) Participants indicated their responses on a check sheet. After tasting and rating the solution, they ate a bread cube to clear their palates. They then sampled all 20 solutions without a break.

At least 24 h after finishing the first session, participants returned for the second, which contained the second conditioning period followed by the posttest. Both were exactly the same as in the first session.

Analysis

Nonparametric statistics were used in all analyses because of substantial departures from normality. Testing was conducted using Wilcoxon tests, with one-tailed probabilities (as indicated) in which the direction of an effect was predicted. Friedman tests were used to detect any effect of color on odor ratings. Although familiarity ratings were collected, as in all subsequent experiments, they are not reported because they revealed little of interest.

Results

Odor Sourness

Each odor was smelled in one colorless and two colored solutions. For each color an odor was smelled in, a sourness difference score was calculated between the pretest and the posttest for both the citric-paired and the sucrose-paired odor. The citric-paired and sucrose-paired difference scores were then subtracted for each color. This produced three scores reflecting the net conditioning effect for citric acid measured in each of the colors. A Friedman test of these scores did not find any effect of color. The median of these three scores was computed to obtain a measure of the net sourness effect, and a Wilcoxon test was used to determine whether this significantly differed from zero. The overall sourness conditioning effect was significant ($Z = 2.73$, one-tailed), with a net increase in sourness of 8.7. This effect is illustrated in the upper panel of Figure 2, in which the median sourness ratings are presented for the sucrose-paired and citric-paired odors, prior to and after acquisition.

Odor Sweetness

The analysis used for sourness ratings was also applied to sweetness ratings. As with sourness ratings, there was no effect of color. The median of the three color condition scores was computed for each participant, and a Wilcoxon test was conducted to see if this score significantly differed from zero. The overall sweetness conditioning effect was significant ($Z = 2.23$, one-tailed), with a net increase in sweetness of 14.7. This effect is shown in the central panel of Figure 2, in which the median sweetness ratings are illustrated for the sucrose-paired and citric-paired odors, prior to and after acquisition.

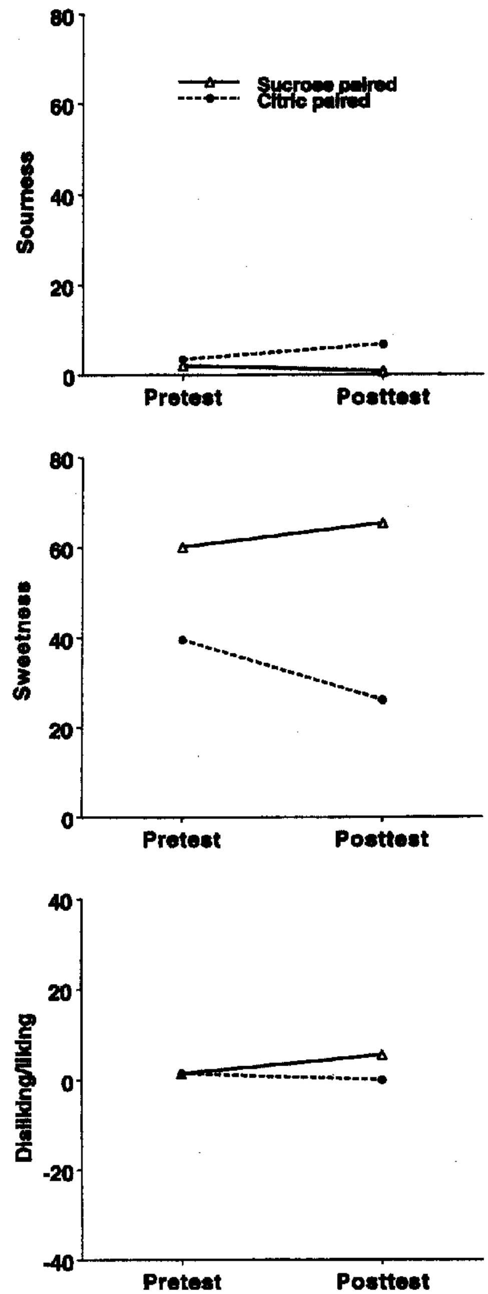

Figure 2. Experiment 2. Median ratings on 100-point scales of sucrose- and citric-paired odors when sniffed on pretest prior to conditioning and on posttest. Top panel: sourness. Center panel: sweetness. Bottom panel: liking.

Liking and Overall Intensity

To determine whether the sucrose- or citric-paired odors had increased in liking, the pretest scores for each color condition were subtracted from the posttest scores for each condition by pairing type (sucrose or citric acid). A Friedman test revealed no significant difference in liking change regardless of the color in which the odor was smelled. When scores were collapsed across color, changes in liking were not significantly different from zero for either the sucrose- or the citric-paired odors. Median liking ratings are shown in the lower panel of Figure 2 for the sucrose- and citric-paired odors, prior to and after acquisition. There were no significant differences for overall intensity either by color condition or by median change between pre- and posttest (sucrose-paired median difference = 0.2; citric-paired median difference = −2.5).

Discussion

One important outcome of this experiment was that the changes in odor perception produced by this brief conditioning procedure were in the same direction and of similar magnitude to those previously produced by the five-session method (Stevenson et al., 1995; 1998). In relation to the subsequent experiments reported here, the present results indicated, first, that introducing interpolated color–taste trials did not detectably affect the tasty-smell effect and, second, presentation of the odors in colored solutions during the pre- and posttests had no detectable influence on the way these odors were perceived.

Experiment 3

The main question addressed by this experiment was whether odor–taste and color–taste learning would differ with respect to extinction. To compare these two forms of learning, we required a common outcome measure. This was accomplished by using an expectancy test, in which participants rated what they thought a solution would taste like on the basis of its appearance and smell—but without actually tasting it.

We used the within-participant design shown in Table 1 for all comparisons in this experiment. This required the use of three odors and three colors, with counterbalancing across participants. One odor was mixed with sucrose (designated Odor 1 or sucrose-paired odor) and presented only during the conditioning phase. The second odor was mixed with citric acid (designated Odor 2 or citric-paired odor) and was also only presented during the conditioning phase. The third odor (designated Odor 3 or extinction odor) was presented in citric acid during the conditioning phase and in water during the extinction phase. The comparison of greatest interest was between Odors 2 and 3 because it would reveal whether the effects of odor-citric pairings during the conditioning phase had been weakened by subsequent odor–water pairings. Exactly the same design was used for the intermixed color trials, for which the three colors were designated Color 1 or sucrose-paired color, Color 2 or citric-paired color, and Color 3 or extinction color.

In a previous study (Stevenson et al., 1998), we found that delaying testing by at least 24 h did not reduce the effects of conditioning when compared with immediate testing. Experiment 3 extended this delay by including a test of retention, in which the majority of participants were retested 1 month after completing the final conditioning session.

Method

Participants

Thirty-three participants completed this experiment.

Stimuli

Odor concentrations were as in Experiment 1. These were more concentrated than those used in Experiment 2 to ensure adequate detection by all participants. Color (red, green, and blue) and taste stimuli (sucrose and citric acid) were as described in Experiment 1a. Odor and taste presentation was as described for Experiment 2.

Procedure

Each participant attended two sessions separated by at least 24 h. The first session contained a pretest and the first conditioning period. The second session contained the extinction period, the posttest, and the expectancy test. Unless otherwise specified, the procedure was exactly as in Experiment 2.

The pretest involved smelling and rating 12 odors. These were the three targets (lychee, water chestnut, and pear) in plain water, in red water, in green water, and in blue water. The conditioning period began with instructions about the task. Participants were asked to "Try to work out what a solution will taste like BEFORE you taste it! Do this in your head and don't mention your 'predictions' to the experimenter." This period contained 8 six-trial blocks (see Table 1). Participants were assigned by order of arrival at Session 1 to one of the nine partially counterbalanced training conditions of pairing type (sucrose vs. citric vs. extinction) with stimulus type (color vs. odor). Each six-trial block contained a solution of Odor 1 in sucrose, a solution of Odor 2 in citric acid, a

Table 1
Design of Training Conditions in Experiment 3

	Odors			Colors			Plain	
Session	SUC+	CIT+	EXT	SUC+	CIT+	EXT	SUC	CIT
Session 1								
8 × six-trial blocks	1 × S	1 × C	1 × C	1 × S	1 × C	1 × C		
Session 2								
12 × four-trial blocks			1 × W			1 × W	1 × S	1 × C

Note. S = 15% w/v sucrose solution, C = 0.16% citric acid solution, and W = tap water only. SUC+ = mixed with sucrose, CIT+ = mixed with citric acid, and EXT (extinguished) = mixed with citric acid in Session 1 and with water in Session 2. SUC and CIT (without pluses) = plain sucrose and citric acid (not mixed with anything). In Session 1 (acquisition) all participants were given 3 colorless odor and 3 odorless color samples within each block of trials. In Session 2 (extinction) they were given 1 odor, 1 color, and 2 taste samples without odor or color within each four-trial block. Table 1 shows the combinations of odors and colors with tastes, or with water only, in each session. Odors and colors are designated in terms of the tastes with which they were combined.

solution of Odor 3 in citric acid, a solution of Color 1 in sucrose, a solution of Color 2 in citric acid, and a solution of Color 3 in citric acid.

Session 2 contained the extinction period, the posttest, and the expectancy test. The extinction period contained 12 blocks of four trials. Each block consisted of a solution of Odor 3 in water, a solution of Color 3 in water, a solution of citric acid, and a solution of sucrose (see Table 1). Order of presentation within a block was again random. The posttest that followed was identical to the pretest.

Participants were then given the expectancy test, for which they were instructed to "Look at, smell and think about each solution carefully, but do not taste it. Then predict what you think the solution would taste like, using the experience you have gained over the course of the experiment." They were then given 12 trials using the small plastic cups from the conditioning and extinction phases of the experiment. Each participant received 2 solutions of blue in water, 2 of red in water, 2 of green in water, 2 of pear in uncolored water, 2 of water chestnut in uncolored water, and 2 of lychee in uncolored water. Presentation order was determined by Williams square. After participants had smelled, inspected, and thought about each solution, they then reported the taste they expected using the same four VAS ratings used to rate the odors—namely, *liking, overall intensity, sourness,* and *sweetness.*

After completing the expectancy test, participants were asked if they would be prepared to return in approximately 1 month to repeat the posttest and the expectancy test. Twenty-nine of the 33 participants agreed to return, and 28 did so. The mean interval between Session 2 and the follow-up was 30.3 days (SD = 6.3; range 21 to 55 days). Returnees were again given the posttest and expectancy test in the manner described previously.

Analysis

All analyses were again nonparametric with median responses used in the associated figures. In addition, key comparisons in the expectancy test also included means and standard errors to provide some indication of variability. This approach was also adopted in Experiment 4.

Results

Expectancy Test

Ratings of odors in terms of the expected sourness, sweetness, and liking for a sample showed a clear difference between sucrose- and citric-paired odors. However, we did not detect any impact of the extinction procedure on odor–taste associations, as is detailed below. The most critical rating, sourness, revealed that presenting the extinguished color in water had decreased the expected sourness for these solutions, but no comparable effect was detected for the extinguished odor.

Sourness ratings. The upper panel of Figure 3 shows how sour particular odor and color samples were expected to taste. It may be seen that by presenting the extinguished color in water, we reduced its expected sourness relative to the citric-paired color. Thus, the citric-paired color (M = 25.3, SE = 6.5) was expected to taste more sour than the sucrose-paired color (Z = 1.99, one-tailed; M = 15.7, SE = 4.8) and critically, the extinguished color (Z = 1.81, one-tailed; M = 18.9, SE = 5.9). There was no difference between the sucrose-paired and the extinguished colors. The pattern was

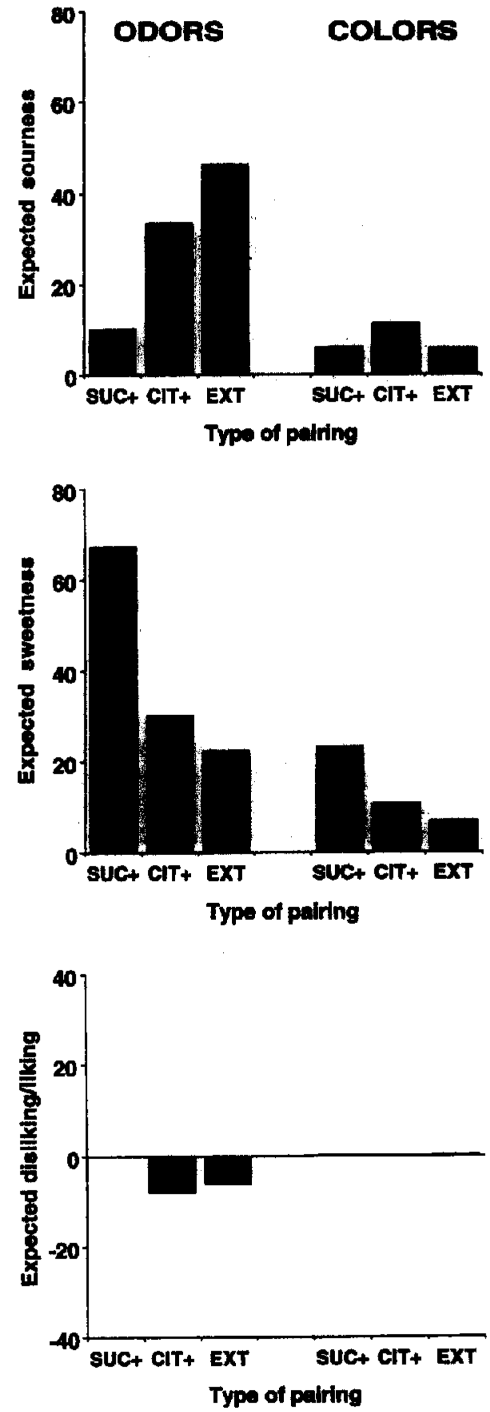

Figure 3. Experiment 3. Median ratings on 100-point scales of the taste properties of a sample expected on the basis of either its odor (left side) or its color (right side). SUC+ refers to stimuli previously paired with sucrose, CIT+ to those paired with citric acid, and EXT to those paired with citric acid during acquisition but with water during extinction. Top panel: sourness. Center panel: sweetness. Bottom panel: liking.

different for odors. Participants expected the citric-paired odor ($M = 38.6$, $SE = 7.6$) to taste more sour than the sucrose-paired odor ($Z = 1.80$, one-tailed; $M = 23.0$, $SE = 6.2$) but no different from the extinguished odor ($M = 45.6$, $SE = 7.4$). However, the sucrose-paired odor was significantly different from the extinguished odor ($Z = 3.12$, one-tailed).

To test the key interaction effects of color versus odor by pairing type (sucrose vs. citric vs. extinguished), we calculated difference scores within colors and odors (e.g., citric-paired minus extinguished scores, for color and odor stimuli separately). These were compared between colors and odors with Wilcoxon tests. The first test compared the citric-paired minus the extinguished stimuli, by stimulus type. The difference was significant ($Z = 1.71$, one-tailed), indicating differential extinction between colors and odors. The second test compared the sucrose-paired minus the extinguished stimuli, by stimulus type. This difference was also significant ($Z = 2.56$, one-tailed), again indicating differential extinction between colors and odors. There was no significant difference between stimulus type for the third comparison—sucrose-paired and citric-paired stimuli—thus giving no indication that the basic learning effect differed between colors and odors.

Sweetness ratings. The central panel of Figure 3 illustrates how sweet participants expected the color and odor samples to taste. Learning about both colors and odors was also detected by these ratings in that participants expected sucrose-paired samples to taste sweeter than citric-paired or extinguished samples. For colors they expected the sucrose-paired color ($M = 25.9$, $SE = 5.6$) to taste significantly sweeter than either the extinguished color ($Z = 2.28$, one-tailed; $M = 14.9$, $SE = 4.5$) or the citric-paired color ($Z = 2.57$, one-tailed; $M = 15.8$, $SE = 4.5$). There was no significant difference between the citric-paired and extinguished colors. The same pattern was observed for odors in that the sucrose-paired odor ($M = 59.3$, $SE = 6.9$) was expected to taste sweeter than the extinguished odor ($Z = 4.15$, one-tailed; $M = 28.1$, $SE = 5.7$) and the citric-paired odor ($Z = 3.29$, one-tailed; $M = 33.4$, $SE = 6.8$). There was no difference between the citric-paired and the extinguished odor.

Liking. Hedonic expectancies are illustrated in the lower panel of Figure 3. These were largely at the indifference point, and there was virtually no difference between different colored solutions on this measure. However, even though small, the median difference between the sucrose-paired and the citric-paired color was significant ($Z = 2.29$, one-tailed; median difference = 1) but not the difference between the sucrose-paired and the extinguished color. There was no significant difference between the extinguished and citric-paired color. For odors, expected liking ratings for the sucrose-paired odor were significantly higher than for the extinguished ($Z = 2.14$, one-tailed) and the citric-paired odor ($Z = 1.88$, one-tailed). There was no difference between the extinguished and the citric-paired odor.

To determine if there was differential responding between colors and odors, we examined the same interaction effects as we did for sourness. Wilcoxon tests revealed that the color-by-odor comparison was significant for the sucrose-paired minus extinguished conditions ($Z = 2.01$, one-tailed), but not for the other two comparisons, sucrose-paired minus citric-paired and citric-paired minus extinguished. The results confirm that the difference between the sucrose and the extinguished condition was greater for odors than for colors, a finding consistent with the conclusion that color stimuli had extinguished, but odor stimuli had not.

Overall intensity. Odor stimuli were expected to taste significantly more intense ($M = 65.8$) than color stimuli ($M = 20.4$; Friedman $F_r(5) = 96.1$). No other differences were detected on this measure.

Repeated Expectancy Test

The pattern of results obtained 1 month later was very similar to that from the initial test. Participants expected the sucrose-paired odor to taste less sour than either the citric-paired ($Z = 2.14$, one-tailed) or the extinguished odor ($Z = 2.95$, one-tailed). There was no difference between the extinguished and the citric-paired odor. For colors, we found that no difference reached significance though the pattern of medians was similar to that in the initial test. As for sweetness ratings, participants expected the sucrose-paired odor to taste sweeter than either the citric-paired ($Z = 2.88$, one-tailed) or the extinguished odor ($Z = 3.81$, one-tailed). There was no difference between the extinguished and citric-paired odors ($Z < 1$). A similar pattern was observed for the colors in that the sucrose-paired color was expected to taste sweeter than either the citric-paired color ($Z = 2.02$, one-tailed) or the extinguished color ($Z = 2.09$, one-tailed). There was no difference between the citric-paired and the extinguished colors ($Z < 1$). For both colors and odors, this pattern was the same as in the initial test.

As for liking ratings, participants expected to like the sucrose-paired odor sample more than either the citric-paired ($Z = 2.11$, one-tailed) or the extinguished ($Z = 1.89$, one-tailed) odor samples. There was no difference between the citric-paired and the extinguished odors. They also expected to like the sucrose-paired color sample more than the citric-paired color sample ($Z = 1.89$, one-tailed), but we found that no other difference reached significance.

Odor Pre- and Posttests

As for the expectancy test, these tests failed to detect any effect of the extinction procedure even though they revealed the standard tasty-smell effect when sucrose- and citric-paired odors were compared. Participants' ratings of the sniffed odors were not influenced by the color of the sample that they were presented. Consequently, the results reported here and shown in Figure 4 are based on data averaged over color. The top panel of this figure shows ratings of odor sourness. In terms of changes in rating from pre- to posttest, the increase for the extinguished odor was significantly greater than for the sucrose-paired odor ($Z = 2.07$, one-tailed). However, neither the difference between the sucrose-paired and the citric-paired odors nor the difference between

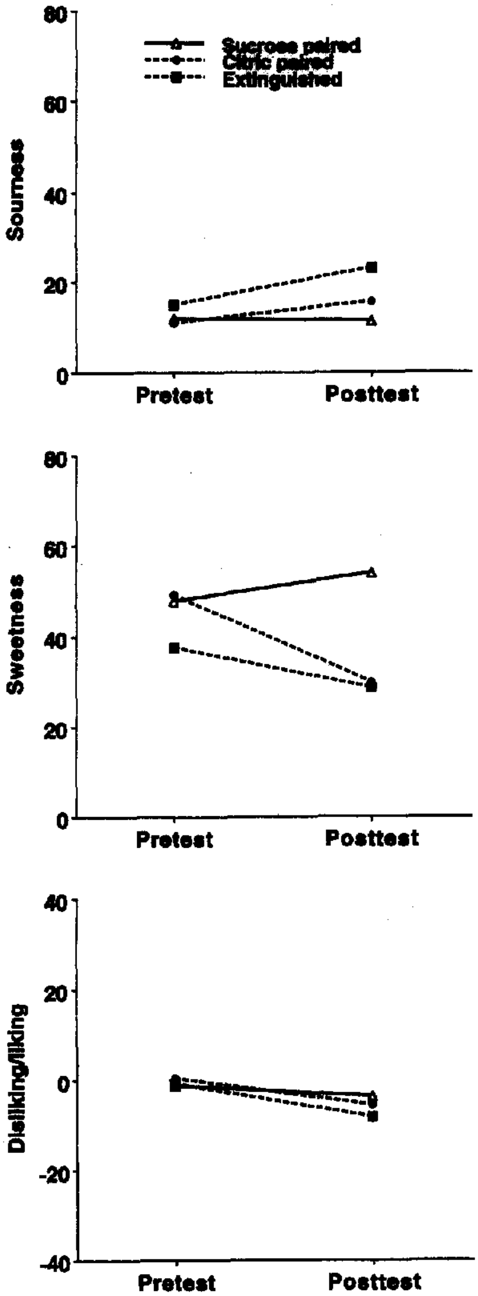

Figure 4. Experiment 3. Median ratings on 100-point scales of sucrose-paired, citric-paired, and extinguished odors when sniffed on pretest prior to conditioning and on posttest. Top panel: sourness. Center panel: sweetness. Bottom panel: liking.

the citric-paired and the extinguished odors was significant. The middle panel of Figure 4 shows odor sweetness ratings. The sucrose-paired odor was judged sweeter than the citric-paired odor ($Z = 2.72$, one-tailed), as was the sucrose-paired odor when contrasted with the extinguished odor ($Z = 3.08$, one-tailed). The difference between the citric-paired and the extinguished odor was not significant. As for the odor liking ratings shown in the bottom panel of Figure 4, there was no significant change from pre- to posttest for the sucrose-paired odor. The citric-paired odor significantly decreased in liking from pre- to posttest ($Z = 2.89$, one-tailed), as did liking for the extinguished odor ($Z = 3.12$, one-tailed). There were no significant changes in overall intensity for any of the three odors (median differences between pre- and posttest for sucrose-paired, citric-paired, and extinguished were 4.5, 4.5, and 0.5, respectively). Exactly the same pattern of results was obtained at 1-month follow-up.

Discussion

The important finding in Experiment 3 was that the extinction procedure had no detectable effect on either odor-based expectancies as to what a sample would taste like or on conditioned changes in perception of an odor. In contrast, the extinction procedure did affect expectancies based on color in the predicted way. Moreover, most of these differences were maintained at 1-month follow-up.

Although these results suggest that odor–taste learning is particularly resistant to extinction, they could have occurred for any of three less interesting reasons. First, participants may have formed stronger associations between odors and tastes than between colors and tastes, so that postextinction differences may have reflected prior differences in associative strength. Second, the change in context from conditioning to extinction may have favored more rapid extinction of color–taste learning. Third, participants may have failed to discriminate as well between the two citric-paired odors as between the two citric-paired colors. Thus, extinction of the odor–taste association may have been retarded by generalization from the nonextinguished citric-paired odor. Experiment 4 was designed to address these issues.

Experiment 4

The aim of this experiment was the same as that of Experiment 3—namely, to compare extinction of an odor–taste association with that of a color–taste association. The procedure was designed to minimize the three problems identified in the previous section by making the following changes. First, a new training task was introduced to promote better acquisition of color–taste associations. In Experiment 3, the low level of color–taste learning may have resulted from use of a task—comparing the current sample with the preceding sample—which may well have competed with that of learning to predict the taste of a sample from its color. In the present experiment, the training task was designed to be compatible with such learning. Participants were asked, following each sample, to indicate the degree to which its taste was surprising. The second major change was to remove the shift in context from conditioning to extinction, which was present in Experiment 3. In the present experiment, the ratio of tastes and the presence of the other colors and odors remained constant across training. This new design is illustrated in Table 2, in which it may also be seen that extinction began in Session 1. The third change was to add a frequency test in which participants estimated how many times they had sampled each color and odor in sucrose, citric acid, and water. Correctly identifying the appropriate combination as having occurred more frequently

Table 2
Design of Training Conditions in Experiment 4

	Odors				Colors			
Session	SUC+	CIT+	EXT	PREX	SUC+	CIT+	EXT	PREX
Session 1								
Block 1	1 × S	1 × C	3 × C	3 × W	1 × S	1 × C	3 × C	3 × W
Block 2	1 × S	1 × C	3 × C	3 × W	1 × S	1 × C	3 × C	3 × W
Block 3	1 × S	1 × C	3 × W	3 × W	1 × S	1 × C	3 × W	3 × W
Session 2								
Block 1	1 × S	1 × C	3 × W	3 × W	1 × S	1 × C	3 × W	3 × W
Block 2	1 × S	1 × C	3 × W	3 × C	1 × S	1 × C	3 × W	3 × C
Block 3	1 × S	1 × C	3 × W	3 × C	1 × S	1 × C	3 × W	3 × C

Note. S = 15% w/v sucrose solution, C = 0.16% citric acid solution, and W = tap water only. SUC+ = mixed with sucrose, CIT+ = mixed with citric acid, EXT (extinguished) = mixed with citric acid in the first two trial blocks and with water in the remaining blocks, and PREX (preexposed) = mixed with water in the first four blocks and with citric acid in the final two blocks. In both sessions each block of trials contained eight colorless odor and eight odorless color samples. The table shows the combinations of odors and colors with tastes or water-only across blocks. Odors and colors are designated in terms of the tastes with which they were combined.

than the infrequent or nonexperienced combinations could provide evidence of discrimination between the citric-paired and extinguished odors.

Method

Participants

Thirty-one participants completed this experiment.

Stimuli

Three of the colors (red, green, and blue), the odors (lychee, water chestnut, and pear), and the tastes (citric acid and sucrose) were the same as in Experiment 1a, and Color 4 (yellow) and Odor 4 (blueberry) were the same as in Experiment 1b. Presentation of stimuli was the same as in Experiment 3.

Procedure

Participants completed an odor pretest and half of the conditioning trials in Session 1, and they completed the remaining conditioning trials plus the odor posttest, expectancy tests, and frequency tests in Session 2. Sessions were again separated by at least 24 h.

A minor change was made to the odor pre- and posttests whereby each odor was presented twice in uncolored water rather than three times, in different colors, as in Experiment 3. More important were changes in the training periods, as outlined previously and shown in Table 2. First, to make the conditioning and extinction contexts as similar as possible, a preexposure condition was introduced, which is labeled PREX in Table 2. This required the additional odor and color. This preexposure condition was included to balance the number of citric acid and water tastes across both training periods. Each of these periods was divided into three 16-trial blocks, in which a sample from each trial contained either one of the four odors or one of the four colors, with or without a taste.

In Session 1, following the odor pretest, each participant sampled one odor and one color three times in sucrose (SUC+), one odor and one color three times in citric acid (CIT+), one odor and one color six times in citric acid and then three times in water (EXT), and one odor and one color nine times in water (PREX; see Table 2). In Session 2, each participant sampled the SUC+ odor and color a further three times in sucrose, the CIT+ odor and color a further three times in citric acid, the EXT odor and color nine times in water, and the PREX odor and color three times in water and then six times in citric acid. Sequences of trials within a block were random.

During training, participants were asked to look at a solution's color, smell it, and think what it would taste like. They then sampled the solution, expectorated, and rated how well their expectation corresponded to the actual taste of the solution ("How well did you predict the taste of the last solution?") using an 11-point scale (anchors: 1 = *very badly;* 6 = *I could not make a prediction;* 11 = *very well*).

Following the second training period, the odor posttest was given, which was exactly the same as the pretest, and then the expectancy test was given. This test was similar to the one in Experiment 3, except that in this test participants looked at, smelled, and rated the expected taste of three samples of each of the four colors and four odors (i.e., 24 in total). Note that, as before, participants did not taste the solutions in this test.

The inclusion of the extra sample on the expectancy test was needed because the same samples were subsequently used in the frequency test. We asked participants to sample and expectorate each of the 24 solutions and to rate them using a 15.3-cm line scale (anchors: 0 = *never,* 15.3 = *very frequently*) to assess how frequently that combination occurred across both sessions of the experiment. Ratings were taken of each color and odor in sucrose, citric acid, and water (the presentation medium).

Data analysis was broadly as it was for Experiment 3. Three changes were made. First, the median of the three ratings for each odor and color in the expectancy test was used for analysis of results from this test. The second change was to provide data on the effects of combining the results of the two extinction experiments using the Z combination method described by Rosenthal (1978). Third, because the frequency test data met the assumptions required for parametric testing, we analyzed the data with an analysis of variance (ANOVA).

Results

The results of main interest were the sourness ratings from the expectancy test. As summarized in Table 3 and shown in detail in the upper panel of Figure 5, color–citric associations were found to be weakened by the extinction procedure, whereas odor–citric associations were not. Thus,

Table 3
Wilcoxon Test Z Values for Sourness Ratings From the Expectancy Tests in Experiments 3 and 4 and the Combinatorial Z Values Resulting From Combining the Test Results From Both Studies (see Rosenthal, 1978)

Comparison	Experiment 3 Zs	Experiment 4 Zs	Combined Zs
Color pairings			
Citric vs. sucrose	1.99*	2.17*	2.94*
Citric vs. extinguished	1.81*	2.93*	3.35*
Sucrose vs. extinguished	0.48	−0.83	−0.25
Odor pairings			
Citric vs. sucrose	1.80*	2.22*	2.84*
Citric vs. extinguished	0.88	−0.29	0.42
Sucrose vs. extinguished	3.12*	1.72*	3.42*
Interaction effects (color vs. odor)			
Citric vs. sucrose	0.76	0.53	0.91
Citric vs. extinguished	1.71*	1.83*	2.50*
Sucrose vs. extinguished	2.56*	1.13	2.61*

*$p < .05$, one-tailed.

this experiment replicated the main finding from Experiment 3. More important, in the absence of extinction (i.e., the CIT+ condition), the expectancy test revealed similar sourness ratings for colors and odors. Furthermore, the frequency test revealed that participants could discriminate between the odors on the basis of the tastes with which they had been mixed, but not between the colors.

Expectancy Test

Sourness ratings. A participant who had learned that solutions of a certain color had always tasted sour should have expected solutions of this color to taste more sour than solutions of other colors. As may be seen in the upper panel of Figure 5, this was the obtained result. Among the color samples, participants expected the citric-paired color to taste most sour. Sourness ratings for the sucrose-paired, the extinguished, and the preexposed colors were much lower. Analysis of these data showed that the citric-paired color ($M = 22.7$, $SE = 4.8$) was expected to taste more sour than both the sucrose-paired ($Z = 2.17$, one-tailed; $M = 6.1$, $SE = 1.9$) and the extinguished color ($Z = 2.93$, one-tailed; $M = 7.8$, $SE = 2.7$), but not the preexposed color, although it did approach significance ($Z = 1.92$; $M = 14.8$, $SE = 4.2$). There were no significant differences between the sucrose-paired, the extinguished, or the preexposed colors.

A different pattern was obtained for the odors, as can be seen in the upper panel of Figure 5. As for the comparable color, the citric-paired odor ($M = 24.9$, $SE = 4.7$) was appropriately expected to taste more sour than the sucrose-paired odor ($Z = 2.22$, one-tailed; $M = 14.0$, $SE = 3.2$). However, the extinguished odor ($M = 22.1$, $SE = 4.5$) was also expected to taste more sour than the sucrose-paired odor ($Z = 1.72$, one-tailed), as was the preexposed odor ($Z = 2.36$; $M = 23.5$, $SE = 4.0$). There were no significant differences between the citric-paired, the extinguished, or the preexposed odors. Finally, there was no difference in expected sourness between the citric-paired color and odor, suggesting a similar degree of learning about colors and odors on this measure.

The key interaction effects of color versus odor were then tested as in Experiment 3. The most crucial test compared whether the difference between the citric-paired and the extinguished stimuli differed significantly between colors and odors. This difference was significant ($Z = 1.83$, one-tailed), thus replicating the result obtained in Experiment 3. A second test addressed whether the difference between the sucrose-paired and the extinguished stimuli differed significantly between colors and odors. Although the medians were in the expected direction, this result failed to reach significance ($Z = 1.13$). A final comparison failed to detect any odor–color difference in the basic learning effect between the sucrose-paired and the citric-paired stimuli ($Z < 1$).

A detailed comparison between the results of Experiment 3 and the present experiment is provided in Table 3. The second and third columns present the Z values from the most important Wilcoxon tests on the expected sourness data for this experiment and for Experiment 3. The fourth column presents the combined Z value calculated by summing the two Z values and dividing by the square root of 2 (Rosenthal, 1978). This combinatorial approach was adopted to see if, overall, the same pattern of effects is observed when the results from the two studies are combined. The pattern is very clear and indicates consistent differences in extinction between the colors and odors.

Sweetness ratings. The central panel of Figure 5 illustrates expected sweetness ratings. Colors and odors reveal a broadly similar pattern, with participants appropriately expecting sucrose-paired samples to taste sweeter than all the others. Analysis of these data showed that the sucrose-paired color ($M = 26.1$, $SE = 5.3$) was expected to taste significantly sweeter than the citric-paired ($Z = 2.87$, one-tailed; $M = 9.3$, $SE = 3.0$), the extinguished ($Z = 3.10$, one-tailed; $M = 5.5$, $SE = 2.1$), and the preexposed color ($Z = 3.04$; $M = 6.1$, $SE = 1.9$). There were no significant differences between the citric-paired, extinguished, or preexposed colors. In a similar pattern, the sucrose-paired odor ($M = 43.7$, $SE = 5.0$) was expected to taste sweeter than the citric-paired ($Z = 1.92$, one-tailed; $M = 30.9$, $SE = 4.7$), the extin-

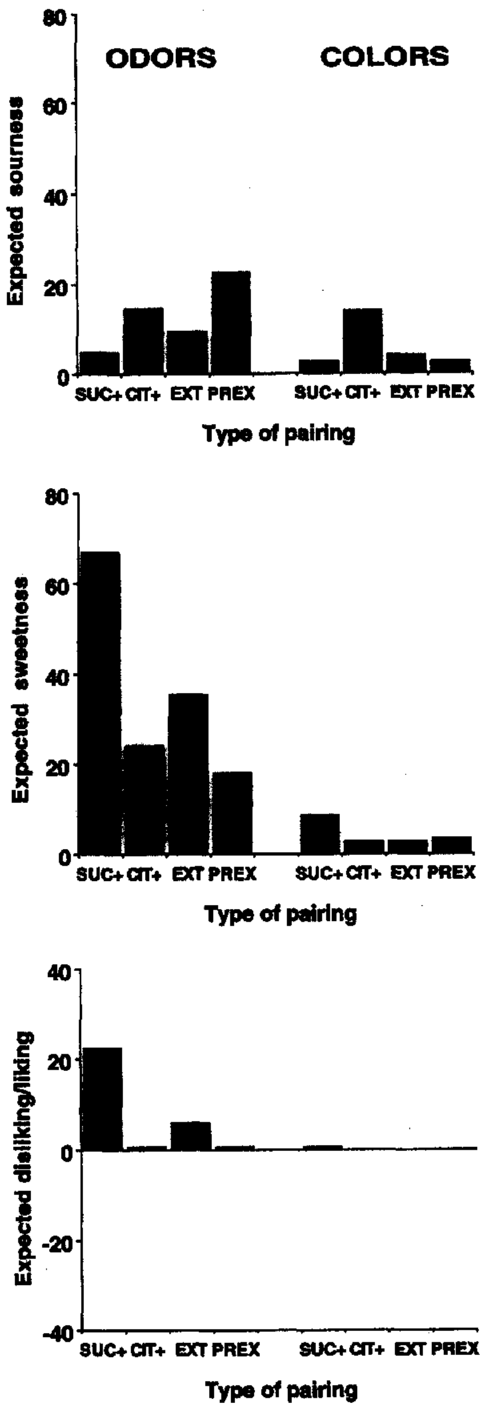

Figure 5. Experiment 4. Median ratings on 100-point scales of the taste properties of a sample expected on the basis of either its odor (left side) or its color (right side). SUC+ refers to stimuli previously paired with sucrose, CIT+ to those paired with citric acid, EXT to those paired with citric acid during acquisition but with water during extinction, and PREX to those paired with water during preexposure and then with citric acid during acquisition. Top panel: sourness. Center panel: sweetness. Bottom panel: liking.

guished ($Z = 3.00$, one-tailed; $M = 25.9$, $SE = 2.1$), and the preexposed odor ($Z = 2.85$; $M = 24.1$, $SE = 1.9$). There were no significant differences between the citric-paired, extinguished, or preexposed odors. Because no prior expectation was held about the behavior of sweetness ratings as a consequence of extinction, and because there were no obvious differences between colors and odors with respect to extinction (as seen in Figure 5), we conducted no further analyses.

Liking. As can be seen in the lower panel of Figure 5, whether participants expected to like the taste of a sample was unaffected by its color. Analysis of these data confirmed that there were no significant differences between the four colors. On the other hand, expected liking was influenced by the odor of a sample. Analysis of these data showed that the sucrose-paired odor was expected to taste more pleasant than the citric-paired ($Z = 2.40$, one-tailed), the extinguished ($Z = 2.03$, one-tailed), and the preexposed odor ($Z = 2.28$). There were no significant differences between these three odors. As in Experiment 3, the interaction effects were examined in the same way as sourness effects. Wilcoxon tests revealed that the color-by-odor comparison was significant for the sucrose-paired minus extinguished conditions ($Z = 1.69$, one-tailed), but not for the citric-paired and extinguished stimuli. However, unlike Experiment 3, the sucrose-paired and the citric-paired comparison was significant ($Z = 2.27$).

Overall intensity. As in Experiment 3, participants expected the odor samples to taste stronger ($M = 61.0$) than the color samples, [$M = 9.3$; Friedman $F_r(7) = 64.0$]. No other differences were found.

Frequency Test

In Figure 6, it may be seen that frequency judgments about odor compounds were related to the actual frequency that an odor had been sampled in a given medium. For example, the top left panel indicates that participants correctly judged the citric-paired odor to have been experienced in citric acid more than in sucrose solution or in water. In contrast, there was no indication that participants were able to judge which color had occurred with which taste. Regardless of their past pairing with tastes, colors were always judged to have occurred more frequently in water than in any other medium. As noted previously, the distribution of these data conformed much more closely to a normal distribution than did the other ratings; thus, they could be analyzed parametrically using 4 (prior pairing: SUC+ vs. CIT+ vs. EXT vs. PREX) × 3 (test medium) repeated-measure ANOVAs.

The overall analysis of odor data revealed a significant interaction between test medium and prior pairing, $F(6, 180) = 5.19, p < .0001$; $MSE = 1197.6$; Huynh-Feldt $\epsilon = .93$. The nature of this interaction was then examined in separate one-way ANOVAs carried out on the data for each type of odor. For the sucrose-paired odor there was a main effect of test medium, $F(2, 60) = 3.46, p < .05$; $MSE = 1297.4$; Huynh-Feldt $\epsilon = .94$. Planned dependent t tests were then conducted on the two comparisons of interest, the

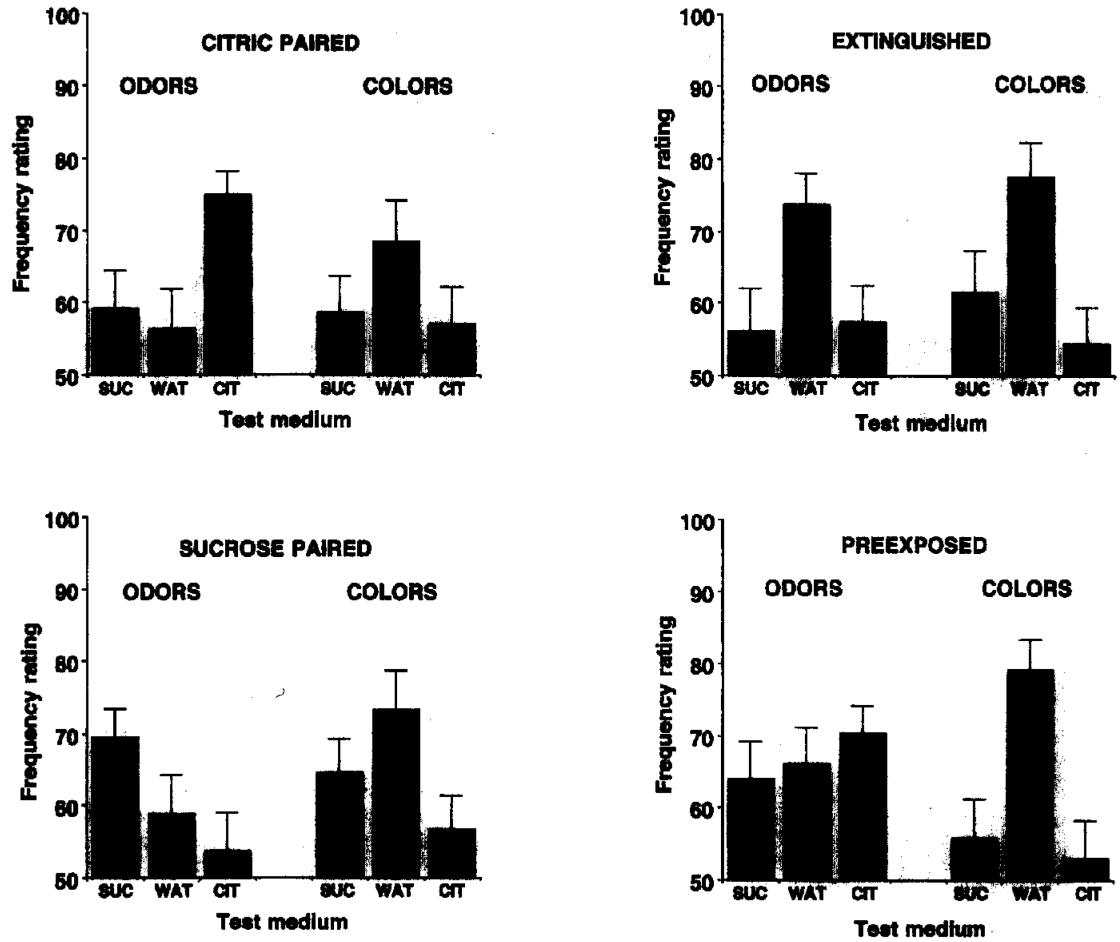

Figure 6. Experiment 4. Mean frequency ratings (plus *SE*) on a 100-point scale for stimuli that had been either paired with citric acid (top left), with sucrose (bottom left), with citric acid and then extinguished (top right), or preexposed with water and then paired with citric acid (bottom right). Data for odors are shown to the left of each panel, and data for colors are shown on the right. SUC refers to frequency estimates made when the stimulus was tasted in sucrose; WAT, when tasted in water; and CIT, when tasted in citric acid.

citric vs. the sucrose medium, which was significant $t(30) = 2.52, p < .025$, and the water vs. the sucrose medium, which approached significance $t(30) = 1.98, p < .06$. These differences suggest that participants could identify that the sucrose-paired odor had occurred most often in sucrose. For the citric-paired odor there was again a main effect of test medium $F(2, 60) = 4.83, p < .025$; $MSE = 1448.6$; Huynh-Feldt $\epsilon = .95$. Planned dependent t tests revealed a significant difference between the sucrose and the citric acid medium $t(30) = 2.47, p < .025$, and between the citric acid and the water medium $t(30) = 3.23, p < .01$. These differences indicated that participants judged correctly that the citric-paired odor had occurred most often in citric acid.

Most important, there was a main effect of test medium for the extinguished odor $F(2, 60) = 4.54, p < .025$; $MSE = 1479.8$; Huynh-Feldt $\epsilon = .96$, and planned dependent t tests revealed a significant difference between the water and sucrose mediums $t(30) = 2.61, p < .025$, and between the citric acid and water mediums $t(30) = 2.80, p < .01$. These differences indicated that participants judged correctly that the extinguished odor had occurred most often in water. Finally, for the preexposed odor there was no significant main effect of test medium, suggesting that participants were unable to identify in which medium this odor had occurred most frequently.

As for judgments of the frequency of color–taste combinations, we found that the overall ANOVA of these data detected only a main effect of test medium $F(2, 56) = 5.69$, $p < .01$; $MSE = 4625.1$; Huynh-Feldt $\epsilon = 1.0$ (2 participants had missing observations). These data confirmed that the pattern of estimated frequencies across test mediums was not detectably affected by the actual frequencies.

Odor Pre- and Posttests

We found a pattern of results in these tests that was similar to that obtained in Experiment 3 and consistent with the data on odor-based expectancies reported previously for this experiment. However, the data were more variable than those from the equivalent tests in Experiments 2 and 3, and fewer differences were found to be significant. Consequently, these data are reported briefly here, listing just those differences found to be significant. For the odor sourness ratings, we found the predicted increases from pre- to posttest for the citric-paired ($Z = 2.09$, one-tailed), the preexposed ($Z = 2.54$), and the extinguished odor ($Z = 2.17$, one-tailed), but we found no significant change in sourness for the sucrose-paired odor. The only significant change in sweetness ratings from pre- to posttest was a decrease in the case of the extinguished odor ($Z = -1.64$, one-tailed). Liking for the sucrose-paired odor increased from pre- to posttest ($Z = 1.72$, one-tailed), whereas liking for the preexposed odor decreased ($Z = -2.44$). Finally, there were significant increases from pre- to posttest in the rated intensity of the sucrose-paired ($Z = 2.81$; median difference = 12.0) and citric-paired odors ($Z = 2.02$; median difference = 9.7), but not for the extinguished (median difference = 9.3) or preexposed odors (median difference = 3.3).

Discussion

Like Experiment 3, this experiment revealed that an extinction procedure that affected a color–taste association had no detectable effect on a comparable odor–taste association. It added to the previous experiment by precluding three alternative accounts of the differential extinction effect. First, because expected sourness ratings did not differ between the citric-paired odor and color, differences in resistance to extinction between odor and color in the present experiment are unlikely to reflect differences in associative strength prior to extinction. Second, the revised design ensured that a nearly identical context was maintained for acquisition and extinction training, yet this did not affect the differential extinction effect. Finally, in Experiment 3 it was not possible to tell whether participants had confused the citric-paired odor with the extinguished odor. The frequency test of the present experiment indicated that participants were able to discriminate between the various odors because estimates of the frequency with which various odor–taste combinations had occurred during training broadly reflected the actual frequencies. In particular, these estimates correctly identified the CIT+ odor as having been mixed most often with citric acid and the EXT odor as having been mixed most often with water.

The dissociation between expectancy and frequency measures of color– and odor–taste learning was particularly interesting. We had anticipated that the results for color from the two tests would be similar, so that participants' inability during the frequency test to indicate the medium (sucrose, citric acid, or water) that had accompanied a given color during training was unexpected. It should be noted, however, that this could be a forgetting effect in that the frequency test followed the expectancy test, in which all the colors were presented in the absence of any taste.

A final point here concerns the PREX stimuli, which were introduced to maintain a constant context for the EXT stimuli (see Table 2). Incidentally, this allowed examination of the possibility that preexposure to either a color or odor, by initially combining them with water, would retard subsequent learning of the color- or odor-citric association. Such an effect might indicate a latent inhibition effect of the kind very widely reported from animal preparations but found less readily in human conditioning experiments (e.g., Lipp, Siddle, & Vaitl, 1992). However, no such effect was observed. In both the expectancy test (see Figure 5) and the odor posttest the PREX odor was rated in a way that was not detectably different from ratings of the CIT+ odor. It should be noted that we presented both odors in citric acid six times during training. This failure to observe latent inhibition for odor–taste learning may have resulted from the unusual way that preexposure occurred. In a standard latent inhibition experiment (e.g., Lipp et al., 1992), preexposure of a stimulus occurs in the absence of other events rather than, as in the present experiment, occurring on trials intermixed with ones that involve conditioning to other stimuli. On the other hand, a marginal latent inhibition effect was found for colors, in that participants did not expect the PREX colored sample to taste as sour as the CIT+ color (see upper panel of Figure 5). Although far from conclusive, these PREX data at least suggest an additional difference between color–taste and odor–taste learning, which deserves further study.

General Discussion

As noted in the introduction, Baeyens and his colleagues (e.g., Baeyens et al., 1995) have claimed that resistance to extinction is a unique property of human evaluative conditioning. In most experiments involving such conditioning, the only judgment participants are asked to make is how much they like or dislike a stimulus. In the present series of experiments, as in our previous research, we have required such judgments in addition to ratings of the perceptual properties of a stimulus. The perceptual ratings, notably sourness and sweetness, proved more sensitive to the various experimental manipulations than did liking ratings. A notable example is provided by the liking ratings for colors in the present series. In the expectancy tests of Experiments 3 and 4, these ratings proved consistently insensitive to the experimental conditions. In this respect, the present results are consistent with the report by Baeyens et al. (1990) that color–taste pairings failed to change liking for a color, even when another measure revealed that the color–taste association had been learned. In the present study, such learning was revealed by the expectancy tests (see Figures 3 and 5).

With regard to liking for the odors, significant changes were sometimes detected. Thus, in Experiment 3, expected liking for the sample with the sucrose-paired odor was greater than liking for the citric-paired or extinguished odors, and in the sniffing tests, liking decreased for the citric-paired and extinguished odors from pre- to posttest. Similarly, in Experiment 4 the sample with the sucrose-paired odor was expected to be more pleasant than the samples with the citric-paired, extinguished, or preexposed odors; and in the sniffing tests, liking for the sucrose-paired odor increased, and liking for the preexposed odor decreased from pre- to posttest. On the other hand, no significant changes in liking were detected elsewhere as a result of conditions that were effective in changing ratings of sweetness and sourness, as, for example, in Experiment 2. Thus, the liking measure was generally less sensitive to experimental conditions than were the perceptual measures. We have found the same result in previous studies of this kind (Stevenson et al., 1995; 1998). This suggests that the main impact of the present training procedures is to change the way that an odor is perceived, with changes in liking as secondary. Changes in liking appear to be an occasional product of the perceptual changes generated by the procedure.

It is nonetheless possible that changes in liking were the primary effect. The relative inconsistency of liking ratings may have arisen because hedonic value is more difficult to measure or inherently more variable. For example, liking ratings may be more sensitive than perceptual ratings to changes in the immediate context. These considerations prompt two questions. First, can changes in affect cause perceptual changes in the chemosensory domain? These are at best likely to be minor because in the clearest experimental example of changing liking for a stimulus without changing its physical characteristics, no perceptual change has been found. Thus, following a sucrose preload, sucrose solutions taste less pleasant but equally sweet (Cabanac, 1971). The complementary question is whether perceptual changes can cause changes in affect. It seems clear that they can, in that, for example, when the intensity of a taste (Kocher & Fisher, 1969; Moskowitz, Kluter, Westerling, & Jacobs, 1974) or a smell (Doty, 1975) is altered by a change of concentration, its affective properties typically change as well. Such evidence suggests that the changes in affective ratings observed here were either a result of changes in the perceived intensity of sweetness and sourness or that they occurred independently. It seems very unlikely that the changes in perceptual attributes occurred as a consequence of changes in liking.

The unusual resistance to extinction of odor–taste learning found in the past two experiments is unlikely to reflect some special aspect of the procedures because the results for extinction of color–taste associations were entirely consistent with those from human conditioning studies using other procedures. Many experiments have examined extinction following an electrodermal conditioning procedure in which a discrete conditioned stimulus (CS) is paired with the arrival of shock (e.g., Fuhrer & Baer, 1980; Mandel & Bridger, 1967; Schell et al., 1991). When the CS is then repeatedly presented on its own, a rapid decrease in responding to the CS occurs within a few trials (Dawson & Schell, 1987).

As there are no obvious procedural explanations for the resistance to extinction of odor–taste associations found in Experiments 3 and 4, we suggest that such resistance reflects the unusual way that odor–taste combinations are encoded. Although the olfactory component of a food or drink stimulates receptors in the nose, while the taste component is sensed on the tongue, the mixture is experienced as being spatially and temporally located in the mouth (Deems et al., 1991). One consequence of this is the sweetness enhancement effect, whereby the mixture of a sweet smelling but tasteless odor with sucrose, which is sampled in the mouth, is judged as tasting sweeter than sucrose alone (Clark & Lawless, 1994; Frank & Byram, 1988; Stevenson, Prescott, & Boakes, 1999). One probable consequence of this perceptual overlap between tastes and odors is the encoding of a configural odor–taste memory (Stevenson et al., 1998).

Contrast this account with color–taste learning. Clearly participants would have no difficulty in telling apart colors from tastes. Therefore the conditions for encoding a configural color–taste association are considerably weakened because the elements are perceptually discrete, as well as being temporally and spatially discrete during acquisition (see Shanks, Charles, Darby, & Azmi, 1998; Shanks, Darby, & Charles, 1998). However, this does not imply that associations cannot be readily formed between colors and tastes or between colors and odors (see Zellner & Kautz, 1990). Rather, the claim here is that what is learned is generally quite different in the two cases.

Does such configural encoding necessarily promote insensitivity to extinction? Following Baeyens et al. (1995), one possibility is that such encoding reduces learning during extinction. If a successive relationship is encoded in terms of two related elements (e.g., *red* → *sour*), then omission of, or change to, the second event is likely to generate perception of a disparity, that is, surprise. This may provide better support for new learning than when a simultaneous relationship has been encoded as a single event (e.g., *sour–lychee*). Any such account faces the problem of explaining the frequency test results from Experiment 4. These results showed that at some level participants had learned that the extinguished odor had occurred more frequently in water than in citric acid, even though this knowledge had no detectable effect on their expectancy or odor test ratings.

This dissociation between frequency judgments and the other measures indicates the need to analyze the effects of an extinction procedure both in terms of what is learned and in terms of how such learning is expressed (i.e., a performance rule). This can be accomplished in two ways. First, it can be assumed, as it has been so far in this article, that odor–taste pairings result solely in configural encoding. Therefore in the case of an extinguished odor—one first paired with citric acid and then with water—we assume that a participant first encodes repeated experiences of *sour–lychee* and then separately of *bland–lychee*. To account for insensitivity of the tasty-smell effect to extinction, a restrictive performance rule is required. Thus, experiencing *lychee* when sniffing may excite all event encodings containing lychee, but only the one containing the most dominant taste affects the way that the smell is perceived.

The disparity between the frequency data and the expectancy test data in Experiment 4 can also be resolved in a second way. In this case, odor–taste mixtures may be encoded configurally, as previously described, but also elementally, as with colors and tastes. This suggestion, peculiar to Experiment 4, stems from the unique training conditions used in that experiment. In this experiment, participants were asked to predict the likely taste of a solution from its color or smell, just prior to tasting. As can be seen in Figure 1, all four odors smelled sweet. Thus participants basing their expectations on the perceptual properties of the odor may have been surprised to find that the solution contained plain water or citric acid. These conditions may have fostered the formation of elemental odor → taste associations. Participants may, therefore, have had access to the following two forms of knowledge about odors: perceptual, based on their smell, and semantic, based on their predictive qualities. Consequently, the type of test dictates what is performed, as an odor may smell sour, but participants may also know that it is predictive of plain water, as with the extinguished odor in Experiment 4.

So far we have considered insensitivity to extinction only with regard to the tasty-smell effect. For comparison with color–taste learning, the expectancy ratings provided the critical measure. In Experiments 3 and 4, participants were asked to rate on the basis of a sample's smell what they expected the sample to taste like. This produced results very similar to those obtained from the sniffing test, particularly in Experiment 3. Following the distinction made in research on recognition memory between familiarity and remembering (e.g., Conway & Dewhurst, 1995), it seems that when faced with the expectancy test, participants mainly relied upon the perceptual properties of an odor to base their judgments. Thus, if a sample smelled sour, they expected it to taste sour. This is probably common practice in our participants' everyday life. The present study indicates that it is not always a reliable one.

In contrast, when a participant sees a colored sample, the color is not perceived as sweet or sour. Consequently, some form of controlled retrieval process has to be engaged to generate an expectancy. The results obtained here for color expectancies approximate to a modified form of the delta-D rule (e.g., Allan & Jenkins, 1980). The delta-D rule is calculated from the difference between the number of confirming instances (P[O/A] and P[−O/−A]) and disconfirming instances (P[−O/A] and P[O/−A]; Shanks, 1985). The modification of the delta-D rule envisaged here is that confirming instances rely solely on P(O/A) and disconfirming instances on P(−O/A). This modification is suggested by the effect of including P(O/−A), that is, unsignaled tastes. This is problematic because if all odor–taste combinations are included (recall that they were not signaled by color), color–taste learning would presumably not have occurred. However, basing the expected sourness of a red sample, for example, on the difference between the frequency with which red samples had been sour (P[O/A]) and the frequency of red nonsour samples (P[−O/A]) yields results similar to those actually obtained in this experiment. In particular, Experiment 4 provided the crucial comparison between the preexposed and extinguished colors, which would have had the same modified delta-D value. The expected sweetness, sourness, and liking for these colors did not differ.

In summary, the present study indicates that an extinction procedure can be ineffective in changing the perceptual property of an odor that has been previously generated by an odor–taste association. This is in marked contrast with the impact of such procedures on other forms of human learning. This unusual feature of odor–taste learning can be principally accounted for in terms of configural encoding (e.g., Gibson, 1969; Kohler, 1930; Rescorla, 1981). More generally, we suggest that similar processes may operate on the way we perceive stimuli in other sensory modalities to be pleasant or unpleasant.

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