Chemosensory Properties of Sour Tastants

R. G. SETTLE, K. MEEHAN, G. R. WILLIAMS, R. L. DOTY AND A. C. SISLEY

Clinical Smell and Taste Research Center and Department of Otorhinolaryngology and Human Communication
School of Medicine, University of Pennsylvania, Philadelphia, PA 19104
and Medical Research Service, Veterans Administration Medical Center, Philadelphia, PA 19104

Received 2 January 1984

SETTLE, R. G., K. MEEHAN, G. R. WILLIAMS, R. L. DOTY AND A. C. SISLEY. Chemosensory properties of sour tastants. PHYSIOL BEHAV 36(4) 619-623, 1986.—In Experiment 1, a taste quality fractionation procedure was used to establish the degree to which sour and non-sour taste sensations are elicited by six concentrations of each of seven acids: citric, hydrochloric, sulfuric, lactic, malic, phosphoric and tartaric. In general, the acids differed significantly in their ability to elicit sour, salty and bitter sensations, with sulfuric and hydrochloric acids producing the smallest proportions of perceived sourness. Bitterness was found to be the largest non-sour sensation produced, followed by saltiness. The perceived taste qualities of the acids were stable across a wide range of concentrations. In Experiment 2 the extent to which the vapors of these test acids produce detectable intranasal non-gustatory sensations at concentration levels used in many human taste experiments was examined. All acids induced clear intranasal sensations at concentration levels used in some suprathreshold taste paradigms. The results suggest that a number of measures of sour taste sensation may be confounded by non-sour chemosensory factors, including intranasal stimulation.

THROUGHOUT the history of taste research, sour (or, in the older literature, acid) has been considered a primary taste quality [1-3]. However, a number of studies suggest that at least some “sour” stimuli produce sensations other than sour, including bitter and salty [10-12], providing one explanation for the apparent common “misidentification” of sour stimuli as bitter in forced-choice test situations [9,15]. To our knowledge, only one study has specifically quantified such sensations [10], and none has examined the potential influence of concentration on this phenomenon. Furthermore, there is some suggestion in the literature that citric acid may elicit more bitterness than hydrochloric acid (see Fig. 2 in [10]), whereas other data [9] suggest the opposite (see Table 2 in [9]). It is conceivable that such differences result from the concentrations used.

In addition to producing more than one taste quality, some acids can induce olfactory and/or trigeminal intranasal sensations [5,6]. For example, hydrochloric acid, the most commonly used sour taste stimulus, is detected by nasal inhalation [7,8]. Other acids used in taste research have received little attention in this regard, despite the possibility that they may produce intranasal cues which potentially confound some measures of taste function.

The present experiments had two main goals. The first goal (Experiment 1) was to evaluate, using a taste quality fractionation procedure, the degree to which sour, salty, sweet and bitter sensations are elicited by a number of concentrations of each of seven acids, including those frequently used in taste research: citric, hydrochloric, sulfuric, lactic, malic, phosphoric and tartaric. Of particular interest was whether or not stronger concentrations of acids elicited proportionately more sour or bitter responses. The second goal (Experiment 2) was to determine whether the vapors of these acids produce detectable intranasal sensations at concentration levels used in a number of human taste experiments. The results of this work provide an empirical basis for more intelligent selection of “sour” stimuli for both basic and applied studies of gustatory function.

EXPERIMENT TASTE QUALITY FRACTIONATION

METHOD

Subjects

Five women and eight men served as subjects in this experiment. These 18 to 33 year old individuals were students at the University of Pennsylvania and evidenced normal taste recognition threshold values [16] (sucrose thresholds <100 mM; NaCl <50 mM; caffeine <10 mM; citric acid <1 mM).

Stimuli

Citric acid, hydrochloric acid, lactic acid, malic acid, phosphoric acid, sulfuric acid and tartaric acid, which met ACS or NRC standards of purity, were dissolved and diluted in deionized water (>18 M ohm). The concentrations used are listed in Table 1 and were previously determined from

1Supported by National Institutes of Health Grant, NINCDS P01-NS-16365.
2Requests for reprints should be addressed to Clinical Smell and Taste Research Center, Hospital of the University of Pennsylvania, 5 Ravidin Institute/Gl, 34th and Spruce Streets, Philadelphia, PA 19104.
stimulus and then estimated the proportions of this intensity attributable to each of five different tastes (sweet, sour, salty, bitter and "other") [10]. To insure that each subject adequately understood this procedure, training was given on two visual tasks which demonstrated the fractionation concept. In the first, a set of lines of differing lengths was presented. Each line was divided into two or three segments of differing colors. For example, one stimulus was a line 15 cm in length which consisted of a blue 5 cm segment, a red 7.5 cm segment, and a yellow 2.5 cm segment. The subject was instructed (a) to assign a magnitude estimate to the overall length of the line relative to the other lines in the set and (b) to then indicate the proportion of the line made up of each color. After demonstrating an understanding of the concept, the subjects were given the second task. This was similar to the first, except that 24 aqueous solutions of yellow and blue food dye (and their mixtures), presented in 12 ml test tubes, were used as visual stimuli. These solutions provided a broad range of blue, yellow and green hues of varying degrees of saturation. After the subjects demonstrated consistent judgments in this task, they were allowed to participate in the taste experiment proper.

In each of three daily test sessions, the subjects received, in random order, the six concentrations of each of the seven acids (Table I) and performed the magnitude estimation and fractionation procedure. Each stimulus consisted of 10 ml of

pilot studies to be isointensive at each of the six intensity levels. Solutions were prepared at the beginning of each week of testing.

Procedures

In order to quantify the proportion of sourness of an acid across a range of concentrations, each subject assigned a numerical estimate to the total perceived intensity of a given

<table>
<thead>
<tr>
<th>Acid</th>
<th>Concentrations (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citric</td>
<td>2.52  4.00  6.34  10.1  15.9  25.2</td>
</tr>
<tr>
<td>Hydrochloric</td>
<td>3.39  5.37  8.51  13.5  21.4  33.9</td>
</tr>
<tr>
<td>Lactic</td>
<td>6.31  10.0  15.9  25.1  39.8  63.1</td>
</tr>
<tr>
<td>Malic</td>
<td>2.99  4.75  7.52  11.9  18.9  30.0</td>
</tr>
<tr>
<td>Phosphoric</td>
<td>3.39  5.37  8.51  13.5  21.4  33.9</td>
</tr>
<tr>
<td>Sulfuric</td>
<td>1.74  2.75  4.36  6.91  11.0  17.4</td>
</tr>
<tr>
<td>Tartaric</td>
<td>2.75  4.36  6.91  11.0  17.4  27.5</td>
</tr>
</tbody>
</table>

In FIG. 1, the proportions of sweet, salty, sour and bitter taste associated with seven acids. For each quality, acids with the same letters did not differ significantly by Duncan's Multiple Range Test (i.e., *p > 0.05*).
solution presented in a 1 ounce soufflé cup (Solo Cup Co., P100). A minimum of 20 seconds was imposed between the stimulus presentations, during which time the subject rinsed twice with deionized water.

RESULTS

To determine if concentration significantly influenced the subjects' proportioning of the total taste intensity of the acids into the sweet, sour, bitter, salty and "other" categories, we performed an acid by concentration two-way analysis of variance (for each quality) on the median proportion assigned to each category by each subject over the three sessions. Concentration had no significant effect on the proportion of the intensity assigned to any of the qualities (Sweet: Concentration Main Effect, F(5,60)=0.61, p=0.69; Concentration by Acid Interaction, F(30,360)=0.74, p=0.84; Sour: Concentration Main Effect, F(5,60)=1.25, p=0.30; Concentration by Acid Interaction, F(30,360)=1.13, p=0.30; Bitter: Concentration Main Effect, F(5,60)=0.74, p=0.59; Concentration by Acid Interaction, F(30,360)=0.85, p=0.69; Salty: Concentration Main Effect, F(5,60)=0.42, p=0.83; Concentration by Acid Interaction, F(30,360)=1.30, p=0.10; All "Other" taste medians were equal to 0 and therefore were not analyzed)*. Thus, we collapsed the data across concentrations to provide a better estimate of the proportioning of the stimulus intensities into the quality categories. The means were then compared using a Duncan's Multiple Range Test for each taste quality. The proportions of the three sessions. The total perceived intensity estimates among the determined range of taste intensities, whereas the second concentration was chosen to represent the approximate midpoint of the determined range of taste intensities, whereas the second was chosen to represent a much lower point.

EXPERIMENT 2: INTRANASAL DETECTABILITY OF ACID VAPORS

METHOD

Subjects

Seven male and six female students (18 to 33 years of age) served as subjects. Eleven had participated in the first experiment.

Stimuli

The seven acids of Experiment 1 were evaluated. By using regression equations developed to describe the total intensity data of Experiment 1, two concentrations of each acid were selected to match the total taste intensity of 8.5 mM and 2.5 mM citric acid, respectively. The first concentration was chosen to represent the approximate midpoint of the determined range of taste intensities, whereas the second was chosen to represent a much lower point.

Procedures

A forced-choice procedure was used to determine the nasal detectability of the acids. Pairs of stimuli, one acid and one water, were presented to the subjects in a manner described elsewhere [6] using 140 ml sniff bottles (6 cm opening, 20 ml of solution/container). A 10-second interval was interspersed between stimuli and a 30-second interval between the pairs of stimuli. Subjects were instructed to sniff the stimuli in each pair and to select the one different from water. The two sets of acid concentrations were tested in separate daily sessions. Eight presentations of each water-acid pair were made during each session.

RESULTS

A subject was considered able to discriminate an acid solution from water if he or she correctly identified 7 or more of the eight water-acid pairs (binomial test, p<0.05; [17]).

*To insure that the stimulus concentrations used in this study (which were previously established in a different set of subjects to be isointensive across acids) were perceived as isointensive by the present subjects, we also performed an acid by concentration two-way analysis of variance on the geometric means of the magnitude estimates of the three sessions. The total perceived intensity estimates among the stimulus were not significantly different (Acid Main Effect, F(6,72)=1.65, p=0.14; Acid by Concentration Interaction Effect, F(30,360)=1.29, p=0.11).
Using this criterion, most subjects discriminated the acid solutions [matched in total taste intensity to 8.5 mM citric acid (Table 2)] from water. A one-way analysis of variance indicated there were no significant differences among the acids in the mean number of correct identifications at these concentrations, \( F(6,72)=0.77, p>0.50 \). When the concentrations of the acids were reduced to a taste intensity equal to 2.5 mM citric acid, only lactic acid was discriminable by a majority of the subjects. A one-way analysis of variance indicated a significant difference among acids in the mean number of correct identifications, \( F(6,72)=3.91, p<0.002 \). A Duncan’s Multiple Range Test showed that the mean number of correct identifications for lactic acid was significantly greater than for all other acids (\( p<0.05 \)).

**DISCUSSION**

The data of Experiment 1 demonstrate three important points: first, that the perceived taste qualities of acids are relatively stable across a wide range of concentrations; second, that the proportion of sourness, saltiness and bitterness (but not sweetness) assigned to acids by subjects differs significantly among the acids; and third, that bitterness is perceived, in most cases, as the largest nonsour component of acids (accounting for roughly 6% to 16% of the total taste) and saltiness the second largest (accounting for 4% to 12% of the total taste).

Our finding that concentration has little or no effect on the relative proportions of sweet, sour, bitter and salty qualities assigned to a number of acids was not anticipated, since the perceived taste qualities of electrolytes, such as sodium and potassium chloride, have long been known to change over concentrations [18]. An increase in the proportion of the intensity called “bitter” would be expected at higher concentrations if explanations for “sour-bitter” confusions such as that suggested by Robinson [15] were correct. Robinson suggests that the term bitter may be associated with unpleasant taste experiences. Since strong sour stimuli are more unpleasant than weak ones, they might be expected to be “misnamed” bitter more frequently than weaker sour stimuli. Alternatively one might have expected a relatively higher proportion of salty responses, at lower concentrations, given the finding that perithreshold concentrations of acids are often termed salty [13], possibly due to the similarity of non-gustatory sensations elicited by salts and acids [4]. However, it is conceivable that the weakest concentrations of acids used in our study may not have been low enough to demonstrate this latter effect, if present.

The finding that acids have differing degrees of nonsour components suggests that the acid selected to represent “sour” may affect the results of a number of taste studies. For example, most electrophysiological studies of “quality specific” fibers have used HCl as the sour stimulus. Since this stimulus has a relatively large salty component, fibers which respond best to NaCl might be expected to also be responsive to HCl. Indeed, data by Nowlis and Frank have found that “salt-best” fibers show a strong response to this acid [14]. If another acid (e.g., phosphoric) had been used, it is possible that “salt-best” fibers would have demonstrated a lower relative responsiveness to “sour” stimulation. If so, generalizations about the breadth of tuning of a fiber would depend upon the specific “sour” stimulus employed.

Despite the fact that the present study demonstrates that the perceived taste qualities of acids are relatively stable across a wide range of concentrations, one should use caution in assuming in other contexts that stimuli differing markedly in total intensity are immune to contrast phenomena and other factors which alter judgments of their perceived qualities. For example, if a relatively strong concentration of an acid whose sour component is low is paired with a relatively weak concentration of an acid whose sour component is high, a subject might report that the first acid is more sour than the second, being unduly influenced by the overall intensities. Whether and to what degree (and in what contexts) such effects occur requires further study.

The results of Experiment 2 indicate that acid solutions at concentrations which have a strong taste intensity are able to be detected by nasal inhalation, presumably via intranasal trigeminal afferents [5,6]. At lower concentrations, which have a moderate taste intensity, only one acid (lactic) was so detected. Thus, experiments in which weak concentrations of these acids are used are not likely to be confounded by such cues, unlike experiments using higher concentrations.

Although the present study is the first systematic examination of the nasal detectability of acids used in taste research, Henkin and Bartter [7] reported that HCl concentrations between 150 and 300 mM were detectable intranasally by one quarter of 41 subjects. In the present study over three-fourths of the subjects were able to detect HCl at a much lower concentration (=10 mM). The basis of the discrepancy between our results and those of Henkin and Bartter [7] is not known, but could conceivably be due to procedural factors (e.g., sniff bottle size, distance of placement of sniff bottle from the nares, etc.) or differences in the purity of stimuli.

In some instances, nasal detection may be responsible for differences observed in the responsiveness to taste stimuli, such as those seen in conditioned taste aversion paradigms. For example, there appears to be less suppression of drinking of HCl (and QHCl) in rats following a conditioned aversion to the ingestion of acetic acid than to that of hydrochloric or citric acid (see Fig. 3; [14]). If the odor and taste of acetic acid form a compound conditioned stimulus, a reduction in the generalization to other stimuli would be expected. Acetic acid was eliminated from the present study because of spontaneous comments of subjects about its odor during pilot work.

In conclusion, the present experiments demonstrate that a number of acids used in taste research do not produce pure sour taste sensations and, furthermore, that such acids can be detected by nasal inhalation at concentrations yielding moderate to strong taste sensations. These findings imply that care should be taken in choosing chemicals representative of “sour” taste, and that several such stimuli should likely be employed in many test paradigms.

**REFERENCES**


