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Metallic Taste and Retronasal Smell

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Abstract

A series of experiments investigated the nature of metallic taste reports and whether they can be attributed to the development of a retronasal smell. Two studies showed that the metallic sensation reports following oral stimulation with solutions of $FeSO_4$ were reduced to baseline when the nose was occluded. No such reduction was seen for $CuSO_4$ or $ZnSO_4$, which were more bitter and astringent, respectively, and less metallic. A discrimination test based on weak but equi-intense levels of $FeSO_4$ and $CuSO_4$ showed that $FeSO_4$ could be discriminated from water with the nose open but not when occluded, but that discrimination of $CuSO_4$ from water was not impaired by nasal occlusion. A discrimination test demonstrated that the headspace over solutions of $FeSO_4$ was not different from water, although some subjects could discriminate $FeSO_4$ solutions from water in the mouth when the nose was occluded, perhaps by tactile or astringent cues. These results confirm that metallic taste reports following oral stimulation with $FeSO_4$ are likely due to development of a retronasal smell, possibly following a lipid oxidation reaction in the mouth. However, metallic taste reports may arise from different mechanisms with copper and zinc salts.

Key words: ferrous sulfate, lipid oxidation, metallic taste, retronasal smell

Introduction

Metallic taste has occasionally been proposed as a basic taste, primary taste or an additional legitimate taste category, outside the widely accepted system of four (or five) basic tastes (see Bartoshuk, 1978). Metallic taste or flavor is commonly reported as a defect in many foods such as oils, cereal products, dairy foods and beer (Borocz-Szabo, 1980). Development of off-flavors presents a challenge to food scientists who attempt to fortify foods with iron compounds (Hurrell, 2002). Metallic tastes arise from contact with metal food packaging (Zacharias and Tuorila, 1979) and processing equipment (Hunzinger *et al.*, 1929; Bodyfelt *et al.*, 1988). Metallic taste is reported in burning mouth syndrome (BMS). Grushka (1987) found metallic taste reports among a sample of BMS patients to be second only to bitterness in terms of phantom qualities reported (27% metallic, 33% bitter and 10% reporting a combination of bitter and metallic). Metallic sensations are also reported from anodal electrical stimulation of the tongue along with sourness and salty tastes (Frank *et al.*, 1986; Frank and Smith, 1991). For divalent salts such as calcium and magnesium, one adjective used to describe these compounds is 'metallic ' (Lawless *et al.*, 2003).

The nature of metallic taste was examined by Hettinger *et al.* (1990). Frequency of reports of metallic sensations from ferrous sulfate solutions in the mouth decreased when the external nares were occluded. Murphy and Cain (1980) showed that nasal occlusion effectively eliminates the odor component of citral solutions placed in the mouth and thus nasal occlusion is generally taken as a method to eliminate stimulation from retronasal smells (see also Mozell *et al.*, 1969). The reduction in metallic reports found by Hettinger *et al.* (1990) implies a retronasal smell origin of the apparent metallic taste from $FeSO_4$. However, this pattern may not occur for other salts. Anecdotal reports from applied sensory evaluation suggest that the effect of placing a copper penny in the mouth is a distinct tactile or taste (oral) sensation in contrast to the effect of rinsing with $FeSO_4$ solutions which is thought to be a retronasal smell (G. Civille, personal communication). Both of these stimuli (a clean penny and $FeSO_4$ solutions) have been suggested as reference standards in applied sensory training of descriptive analysis panels. The possibility of a metallic taste or tactile sensation that is different for copper as opposed to iron salts is examined in this report. Metallic taste has also been reported in response to the nonvolatile intensive sweetener, acesulfame-K (Schiffman *et al.*, 1985), further supporting the possibility of a gustatory rather than olfactory origin of some metallic taste reports.

Whether all metallic tastes are olfactory in nature remains an open question. We extended the approach of Hettinger *et* *al.* (1990) by employing intensity ratings, rather than frequency counts of qualitative reports. We further included other divalent salts, including copper sulfate, calcium sulfate and zinc sulfate. Discrimination of copper and iron salts from water was tested with and without nasal occlusion, to provide a semantic-free check on the intensity scaling results. Finally, we examined the perception of the head-space over ferrous sulfate solutions to examine whether there was any perceivable orthonasal smell. None was evident.

Experiment 1: evaluation of ferrous sulfate, copper sulfate and calcium sulfate with and without nasal occlusion

The purpose of this study was to re-examine the finding of Hettinger *et al.* (1990) using intensity ratings rather than simple yes/no quality reports and to examine whether a similar effect is seen for other divalent salts (copper and calcium). Control conditions were included to test the effectiveness of the nasal occlusion in reducing retronasal aroma perception. These included a stimulus containing lemon odor (flavor) which was expected to be reduced or eliminated by nasal occlusion, a sucrose solution which was expected to be unaffected, and their mixture.

Methods

Subjects

Twenty-four healthy adults were recruited from the Cornell University campus. Informed consent was obtained and a token incentive was paid at the end of the second session. No subjects had any reported problems in taste or smell.

Materials

Solutions consisted of: deionized water; 0.1 M sucrose; 0.05% natural lemon flavor (David Michael & Co., Philadelphia, PA); a mixture containing 0.1 M sucrose and 0.05% lemon flavor; 0.0003 M and 0.003 M $FeSO_4$; 0.03 M and 0.1 M $CaSO_4$; and 0.0003 M and 0.001 M $CuSO_4$. Calcium sulfate solutions were near their solubility limit so the higher concentration is approximate. Rinse water and cups for expectoration were provided. Unsalted crackers and water rinses were provided as palate cleansers between samples. The 15 ml samples were presented at ~22°C. Concentrations of iron and copper sulfate were chosen on the basis of pilot work to produce similar overall perceived intensities.

Procedure

Instructions and responses were communicated via Compusense Five (Guelph, Ontario, Canada). The random orders of samples and random blinding codes were provided by the Compusense program. Panelists participated in two conditions: one in which the samples were tasted and expectorated with the nose open to allow retronasal aroma perception and the second in which Speedo® swimmer's noseplugs were worn to eliminate retronasal smell. Subjects were instructed to place and wear the noseplugs so that they permitted no airflow from attempts at nose breathing. Order of the two nasal conditions was counterbalanced.

Panelists were untrained and naive as to the hypotheses of the study. They were given one practice questionnaire with a sample of 0.1 M sucrose. Perceived intensity was rated on a 15 point anchored category scale with boxes labeled only as 'no taste' at the left end (=1) and 'extremely strong taste' at the right end (=15). Ratings were indicated by checking a box with the computer mouse. Scales were labeled with the word bitterness, sweetness, metallic, lemony, salty, or 'other.'

Data were exported to a spreadsheet and then analyzed using SYSTAT 5.0 for basic statistics and analyses of variance (ANOVA). ANOVAs were conducted on the six ionic samples (chemical, level and nose condition as fixed factors, subjects random, a mixed model with repeated measures) and on the sucrose, lemon, water and mixture samples (sucrose level (present/absent), lemon level (present/absent) and nose condition as fixed factors, subjects random). Critical alpha levels were set at 0.01 and obtained P-values were less unless reported otherwise.

Results

Means for the six ionic samples are shown in Figure 1 for metallic and bitter responses. Other reported tastes were low and near the level for water. The three chemicals differed in metallic taste and also with level [interaction $F(2,42) = 5.40$], with $FeSO_4$ being the most metallic.

Nasal occlusion markedly lowered metallic ratings of $FeSO_4$, but left the other stimuli largely unchanged [nose condition by substance interaction $F(2,42) = 17.19$]. The 1 mM $CuSO_4$ stimulus was rated as metallic even with the nose closed [compared with water, paired $t(24) = 2.87$, $P = 0.009$; sign test $P = 0.008$]. Bitterness ratings were highest for $CuSO_4$ and increased for this substance as a function of concentration [interaction $F(2,46) = 7.26$]. A small effect of nasal occlusion was seen for bitterness [$F(1, 23) = 5.52$]. This decrease was in the range of 15–20% as opposed to a much larger 50–75% decrease for metallic ratings of $FeSO_4$.

The control conditions demonstrated the effectiveness of the noseclips in minimizing retronasal smell. 'Lemony' ratings decreased when the nose was closed for the samples containing lemon flavor (Figure 2) although some residual impression was left in the mixture [interaction of nose condition by lemon factor $F(1,23) = 39.8$]. Sweetness intensity was largely determined by the presence of sucrose, although there was a slight enhancement with lemon flavor alone, a case of gustatory referral [interaction of sucrose by lemon flavor $F(1,23) = 37.63$]. There was a small reduction in sweetness with nasal occlusion, largely due to the reduction in referred sweet taste in the lemon-only sample [$F(1,23) = 5.58$]. Overall, the reduction in intensity ratings for the vola-

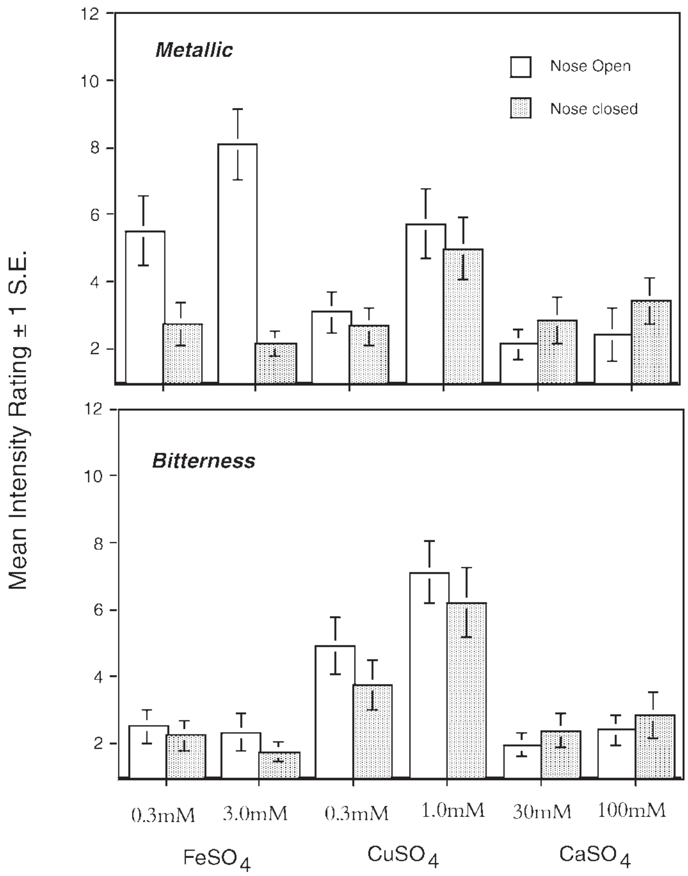

Figure 1 Mean intensity ratings ± 1 SE for metallic and bitter ratings for ferrous, cupric and calcium sulfate. A significant decrement in metallic intensity was noted for FeSO4 but no other compounds or for bitterness ratings.

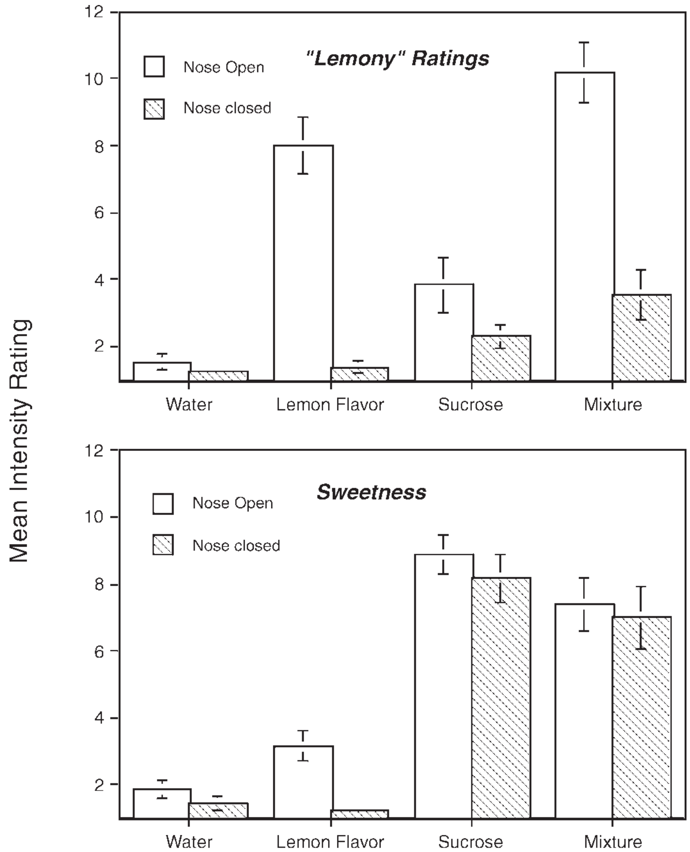

Figure 2 Control conditions for Experiment 1. Mean intensity ratings ± 1 SE for 0.1 M sucrose, 0.05% lemon flavor and their mixture. Nasal occlusion decreased intensity ratings of lemon stimuli but not sweetness of sucrose.

tile lemon flavor showed the expected elimination of olfactory sensations.

Experiment 2: evaluation of ferrous sulfate, copper sulfate and zinc sulfate with and without nasal occlusion

The purpose of this study was to replicate the conditions seen in Experiment 1 but with use of a labeled magnitude scale (LMS) instead of a category scale. Recent arguments have proposed that the LMS is a more valid and sensitive scaling method and helps provide a stable frame of reference between subjects (Bartoshuk, 2000). We also examined another divalent metallic salt, zinc sulfate. The properties of $ZnSO_4$ had been recently studied by Keast (2003), but he did not evaluate metallic taste. One additional modification was to provide training with reference standards for the rated attributes as is commonly done in applied sensory testing, to help align the participants' concepts for the different taste words (Lawless and Heymann, 1998). A deionized water control stimulus was also introduced.

Methods

Subjects

Twenty-eight healthy adults (15 male,13 female, ages 19–34) were recruited from the Cornell community. Informed consent was obtained and a token incentive was paid at the end of testing. None had any reported problems in taste or smell.

Materials

Reference solutions consisted of deionized water, 0.003 M $FeSO_4$ for metallic, 0.00009 M quinine sulfate for bitterness, 0.32 M NaCl for salty, 1% monosodium glutamate for *umami*, 0.019 M citric acid for sour and 1 g/l aluminum ammonium sulfate (alum) for astringency. Following pilot testing to establish approximately equal perceived sensory intensity, the following concentrations and solutions were used in the final test: 1 and 3 mM $FeSO_4$, 0.3 and 1 mM $CuSO_4$ and 0.3 and 3 mM $ZnSO_4$ plus deionized water (16.5–18 MΩ resistance, with 0.2 μm filter). Rinse water and cups for expectoration were provided. Unsalted crackers were provided and the use of rinses and crackers as palate cleansers between samples was encouraged. The 15 ml samples were presented at ~22°C in random order and labeled with three-digit random codes. Samples were made the day before testing and stored at 6°C. Spring water served as the rinse. Pacing in the formal test was approximately two samples per minute with at least 30 s for rinsing between samples.

Procedure

Subjects were first given the reference solutions for training and were familiarized with the procedure. Blind presentation of the samples followed and they were questioned as to the main attributes of the samples. Retasting was done if mistakes were made until the subject could correctly match the reference sample to its primary training word. Testing proceeded in the same session in isolated test booths. Data were collected using Compusense Five (Compusense, Guelph, Ontario, Canada). Subjects rated the intensity of the attributes metallic, bitter, astringent and sour on a labeled magnitude scale (Green *et al.*, 1993) with the upper end anchor representing the strongest imaginable sensation. An 'other' category was provided for any sensations beyond the four labeled scales. Pilot testing showed that these four words were most frequently chosen to describe the stimuli and that others were rarely used. Two counterbalanced conditions were tested, one with the nose open and one with the nose occluded by nose clips (Spiro No. 2110; Spirometrics Medical Equipment, Grey, ME).

Data were exported to a spreadsheet and then analyzed using SYSTAT 5.0 for basic statistics and ANOVA. ANOVAs were conducted on the seven samples by two nasal conditions (fixed factors, subjects random, a mixed model with repeated measures). All F-tests were confirmed by MANOVA (Wilk's lambda). Comparisons of specific means were done with Bonferroni-corrected paired t-tests. Critical alpha levels were set at 0.05 and obtained P-values were <0.05 unless reported otherwise.

Results and discussion

Figure 3 shows a reduction in metallic ratings of $FeSO_4$ with nasal closure. This reduction was not evident for any other test compound [condition × compound interaction, $F(6,162) = 8.97$]. No significant reductions in bitter or astringent ratings was seen as a function of nasal condition, nor any interaction effects. The compounds differed in bitterness [$F(6,162) = 9.60$] with ratings higher than the water control for the higher levels of $CuSO_4$ and $ZnSO_4$. The same was true for astringency [$F(6,162) = 10.48$]. Ratings for sour (not shown) were low and not different from water, except for the higher level of $CuSO_4$ [mean of 10.2 versus 4.8, $t(27) = 2.52$].

As seen in Experiment 1, $FeSO_4$ was unique in producing a metallic response that was greatly reduced by nasal closure, implicating a retronasal olfactory origin of this apparent taste property. The effect persisted in spite of methodological changes in scaling and instructions.

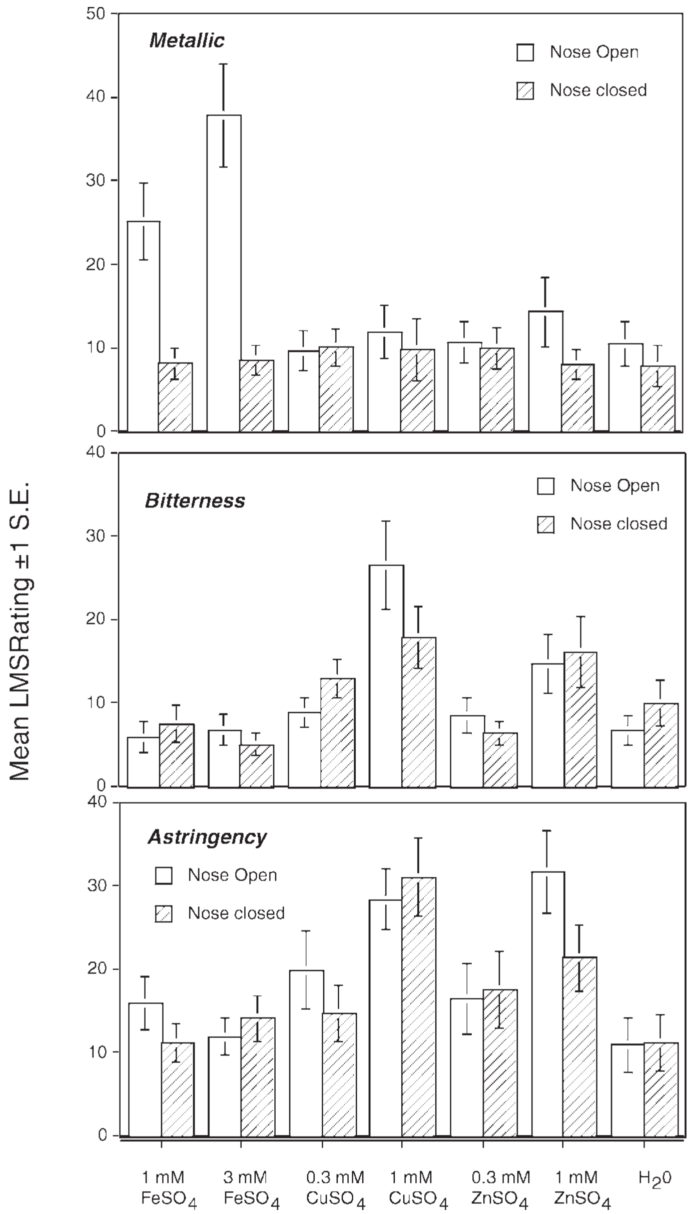

Figure 3 Mean intensity ratings ± 1 SE for metallic and bitter ratings for ferrous, cupric and zinc sulfate. A significant decrement in metallic intensity was noted for $FeSO_4$ when the nose was occluded.

Experiment 3: discrimination of ferrous sulfate and copper sulfate from water with and without nasal occlusion

This experiment was conducted to examine whether weak solutions of $FeSO_4$ and $CuSO_4$ could be discriminated from water when the nose was open or closed. If $FeSO_4$ could be discriminated on the basis of a retronasal smell, then the discrimination should become more difficult or impossible when the nose is occluded. Also this discrimination test (the duo–trio procedure) is a matching-to-standard task and does not rely on any semantic label such as 'metallic'.

Methods

Subjects

Fifty-four participants (age 19–35 mean of 25 years, 19 male, 35 female), mostly students, were recruited from the Cornell campus. All were non-smokers and free from anosmia by self-report. Subjects were untrained and naive to the purposes of the study. Informed consent was obtained and a token incentive paid at the conclusion of the study.

Materials

Test solutions consisted of the following compounds and concentrations: 0.5 mM $FeSO_4$, 0.3 mM $CuSO_4$, 0.1 M sucrose and 0.03% natural lemon flavor (David Michael & Co., Philadelphia, PA). Chemical stimuli were reagent grade and prepared daily in deionized water. Concentrations were chosen to find a low level confusable with water. Solutions were presented as 20 ml samples in 60 ml cups at room temperature, ~22°C. Solutions were made the same day as testing. Deionized water served as the rinse.

Procedure

Subjects completed eight duo–trio tests in a single session, four compounds in two conditions. The duo–trio test presented a reference sample for inspection and then a pair of samples to be discriminated, one of which matched the reference. In one condition, the four tests against water were performed with the nose open and in a second condition, with the nose closed by Speedo® swimmer's nose clips. Subjects rinsed twice with deionized water before beginning the test and between each stimulus. After the iron and copper salts, they also rinsed with 0.005 M sucrose to help eliminate carry-over effects and lingering tastes (Zacarias *et al.*, 2001). The sucrose rinse was not used with the other samples as they were easily removed from mouth and left little or no residual sensations. All samples were sipped and expectorated. Order of testing conditions was counter-balanced as were orders of presentation. Order of the test stimuli was randomized. Sessions were conducted on a one-to-one basis to insure that subjects rinsed. Responses were given verbally and recorded. The total duration of a session was ~15 min.

Numbers correct were compared to binomial tables (Lawless and Heymann, 1998) for statistical significance above chance. Differences between conditions were compared using the IFProgram for comparison of d′ values (Institute for Perception, Richmond, VA, 2003; see Bi *et al.*, 1997).

Results and discussion

Numbers of correct responses and d′ values are shown in Table 1. In the nose open condition, all stimuli were discriminated from water. As expected, the lemon sample was easily discriminated from water (51/54 correct) and closing the nose eliminated discrimination (28/54, not different from chance). $FeSO_4$ was also not discriminated from water when the nose was closed, consistent with the notion that a retronasal smell develops when $FeSO_4$ is introduced in the mouth. A very different pattern was seen for $CuSO_4$ which was discriminated from water both the with nose open and closed. Sucrose was discriminated at about the same level in both conditions (32/54 and 34/54, no difference in d′ values).

Table 1 Numbers of correct judgments and d′ values

	0.5 mM $FeSO_4$	0.3 mM $CuSO_4$	0.1 M sucrose	0.05% Lemon
Nose open				
Number correct	41a	34a	34a	51a
d′	2.08b	1.30	1.30	3.95b
Nose closed				
Number correct	28	43 a	32	28
d′	0.45	2.33	1.07	0.45

$n = 54$.
[a]According to binomial tables, 34 or more correct judgments are significantly above chance.
[b]Significant difference from the closed condition, $P < 0.05$.

The cues in the discrimination of copper from water are unclear but could involve taste or tactile sensations. As shown in Experiment 1, $CuSO_4$ has some metallic taste that is not eliminated by nasal closure. $CuSO_4$ has some bitter and astringent properties so it is possible that a taste or tactile cue is present. Thresholds for copper salts were not affected by nose closure in a previous study (Zacarias *et al.*, 2001). The emergence of different sensory qualities may be concentration-dependent. Sensory cues may change as concentration increases. Future work should examine discrimination across a range of concentrations of both test compounds, with explanatory corroboration by scaling or descriptive analysis by the same test subjects to see what sensory cues are available.

Experiment 4: discrimination of ferrous sulfate from water by sniffing and by tasting with nasal occlusion

The metallic ratings seen in Experiments 1 and 2 could have resulted from an orthonasally perceived metallic smell originating from the solutions and perceived as they were sipped, before they entered the mouth. To examine this possibility a discrimination test was conducted comparing the headspace over $FeSO_4$ solutions to a water control. The purpose of this experiment was to see whether any metallic smell could be detected orthonasally over the headspace of $FeSO_4$ solutions. A concentration halfway between the two stimuli use in Experiment 1 was employed, which would be expected to produce a clear retronasal metallic sensation. Solutions were also tasted with the nose occluded to see if there were any residual sensations from $FeSO_4$ once the smell was eliminated. As in Experiment 1, sucrose and lemon flavor controls were included for comparison. Taste and odor intensity ratings were also obtained to provide a more direct comparison to Experiments 1 and 2.

Materials and methods

Subjects

Fifty healthy adult subjects (16 male, 34 female, ages 19–75, mean 27.9, SD 11.4 years, three smokers) with no self-reported problems in smelling participated. Informed consent was obtained and a token incentive was paid.

Stimuli

Stimuli consisted of 0.1 M sucrose, 1 mM $FeSO_4$, 0.05% lemon aroma and deionized water which also served as the diluent. Samples that were sniffed in the same-different task were 200 ml samples in ~500 ml opaque plastic bottles with a flip-top lid. Samples rated for odor intensity were kept in 120 ml amber glass jars with teflon lined caps and allowed to equilibrate between sampling. All bottles were cleaned by rinsing four times with methanol, ethanol and deionized water. Tasted samples were 20 ml in 60 ml plastic cups served at ~22°C. Subjects rinse three times with deionized water between tastings. All samples were labeled with random three-digit codes.

Procedure

Two conditions were employed, sniffing and tasting with the nares pinched shut by a Speedo® swimmer's nose clip. In both conditions, subjects performed a simple same/different judgment, comparing each stimulus to a deionized water control. The same/different procedure compares favorably in sensitivity and power to other general discrimination tests such as the triangle or duo–trio procedure (Rousseau *et al.*, 1998). A replicate judgment was performed. The frequency of judgments of 'different' when water was compared to itself was used as a baseline for statistical comparisons using binomial tests with $P < 0.05$ as a criterion, with replicates analyzed separately.

In a separate session, subjects ($n = 49$) sniffed the headspace over the solutions in brown glass jars and rated odor intensity on a 15-point anchored category scale (no odor = 1, very strong odor = 15). They also rated taste intensity with the nose occluded on a 15-point anchored category scale (no taste = 1, very strong taste = 15). Data from the intensity ratings were analyzed by repeated-measures ANOVA with stimulus and condition (taste/odor) as factors and subjects random. Tukey/Kramer tests were used for comparisons of means.

Table 2 Frequency of 'different' judgments in the same–different test

	1 mM $FeSO_4$	0.1 M sucrose	0.05% Lemon	Water
Taste (nose closed)				
Rep 1	23	50a	21	13
Rep 2	28a	50a	16	10
Smell (headspace)				
Rep 1	21	21	48a	19
Rep 2	10	15	49a	16

$n = 50$.
[a]Significant difference from the water condition for that replicate, $P < 0.05$.

Results and discussion

Frequency counts of 'different' judgments are shown in Table 2. In the smell condition, only the lemon odor was judged 'different' from water at a higher rate than water compared to itself (binomial tests, $P < 0.001$). The smell of sucrose compared to water and of $FeSO_4$ compared to water was not different from the water compared to itself. In the nose-closed tasting condition, the sucrose was judged 'different' more often than the water compared to itself, as expected. The $FeSO_4$ sample also was called 'different' with significantly higher frequency than the water control, although this discrimination was by no means universal (lower than the sucrose control, binomial tests, $P < 0.05$). Rating data (Figure 4) were consistent with Experiments 1 and 2. Rated taste intensity of the $FeSO_4$ solution was not different from water when tasted with the nose closed and only sucrose showed a significantly higher taste rating. Odor ratings over the headspace of the solutions were not different from water [except for the lemon odor, interaction $F(3,144) = 121.5$, $P < 0.001$]. Although there appears to be little or no smell to a solution of $FeSO_4$, in the mouth there are still cues that allow at least some individuals to distinguish it from water, even without retronasal smell. As there was no difference in taste intensity from water, the same/different results are likely to be due to a mouthfeel cue. Mixtures of $FeSO_4$ with saliva develop a white flocculent precipitate, possibly showing that $FeSO_4$ will precipitate salivary proteins, an action that is associated with causing an astringent sensation (Kallikathraka *et al.*, 2001; Horne *et al.*, 2002).

General discussion

These results confirm the original finding of Hettinger *et al.* (1990) implying a retronasal olfactory metallic sensation following stimulation with $FeSO_4$. Whether other metals and metal salts share this mechanism is open and the possibility exists of other tastes or mouthfeel sensations being labeled as metallic. One subject in Experiment 1 reported the

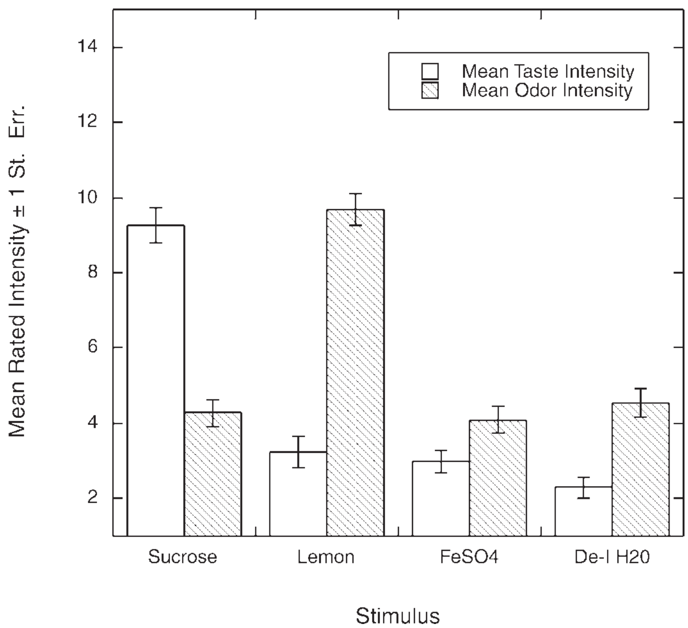

Figure 4 Mean intensity ratings ± 1 SE for taste intensity (nose occluded) and odor intensity (orthonasal, sniffed over the headspace) for 0.1 M sucrose, 0.05% lemon extract, 1 mM $FeSO_4$ and deionized water.

taste of both $CuSO_4$ solutions to produce a 'metallic feeling on the tongue, *not a taste*' (italics inserted). This subject refused to rate $CuSO_4$ as metallic above zero and used an open-ended 'other' category to report this observation. Whether an oral sensation from copper sulfate is tactile or gustatory in nature could be tested by stimulating nongustatory areas, an approach taken by Green (1993) and Breslin *et al.* (1993)to argue that astringency is tactile rather than gustatory. Qualitative observations in our laboratory indicate that a cut copper penny (post-1981) with an exposed the zinc core, produces a metallic, sour, electrical sensation that is much stronger than simply placing a clean intact copper penny in the mouth. This sensation, derived from metals with different electrical potentials, may bear some resemblance to the sensations from anodal stimulation. We plan to examine the possible resemblance of chemical and anodal electrical stimulation using descriptive analysis methods (Lawless and Heymann, 1998).

Because there is little or no orthonasal smell in the headspace over $FeSO_4$ solutions it is possible that metallic smelling compounds develop in the mouth perhaps by $FeSO_4$ catalysis of lipid oxidation. Such a process is consistent with observations from the food literature showing development of metallic smelling compounds from oxidation of linoleic acid or similar precursors. Gas chromatographic sniff-port analysis points to several compounds in foods and beverages having metallic aroma, including *trans*-4,5-epoxydecenal, (Z)-1,5-octadien-3-one and 1-octen-3-one (Guth and Grosch, 1990; Hinterholzer and Schieberle, 1998; Hinterholzer *et al.*, 1998; Buettner and Schieberle, 1999). These compounds are similar to well-known unsaturated carbonyl compounds which are aromatic end-products of lipid oxidation in foods that is catalyzed by exposure to metals such as copper or iron, causing unpleasant flavors. *Trans*-4,5-epoxydecenal itself has been proposed as an oxidation product of linoleic acid (Guth and Grosch, 1990). It is therefore conceivable that the metallic taste noted after rinsing the mouth with $FeSO_4$ is also due to the production of aromatic compounds resulting from the oxidation of lipids or phospholipids in saliva. The compounds found in GC analysis have very low thresholds (very high odor potency). Even a small amount of phospholipid from cell membranes of sloughed epithelial cells could provide an adequate substrate for iron catalyzed oxidation. The odor thresholds for epoxydecenal have been estimated at 0.12 μg/l (0.12 p.p.b.) in water orthonasally and 0.015 μg/l (0.015 p.p.b.) retronasally (Buettner and Schieberle, 2001). The lower retronasal threshold is of some importance if this compound is indeed one of the causes of metallic 'taste'.

Lipid oxidation and the special case of metallic flavor should be differentiated. In dairy science, a well-known flavor defect occurs due to oxidation of milk fats (especially phospholipids) following exposure to metals or metal salts. Due to a tendency to name such defects after their origins or mechanisms, some confusion arises as to the perceptual nature of oxidized defects, which are variously described as papery, cardboard-like, painty, tallowy, fishy and metallic. Bodyfelt *et al.* (1988) in their extensive treatise on sensory properties of dairy products, suggest differentiation of oxidized flavor notes and metallic off-flavor, stating 'consideration should also be given to the metallic off-flavor which is frequently differentiated from the oxidized defect. The metallic defect is characterized by an astringent, metallic sensation which is similar to that observed when an iron nail or metal foil is placed in the mouth' (p. 72). They go on to cite an early study by Hunzinger *et al.* (1929), who examined a variety of metals and alloys used in dairy processing and found iron and copper to be the most detrimental. Copper lactate, for example, was reported to have bitter, puckery, astringent and metallic taste. The reference by Bodyfelt *et al.* (1988) to metals placed in the mouth is also consistent with the use of a copper penny as a reference standard and that this sensation may be different from the retronasal smell evoked by $FeSO_4$.

The semantic and conceptual boundaries of what constitutes a metallic sensation remain unclear at this time. Note that the metallic response to $CuSO_4$, which was seen in Experiment 1, was absent from Experiment 2 in which $FeSO_4$ was introduced in a training session as a metallic reference standard (no such standards were given in Experiment 1). The presentation of $FeSO_4$ as a specific and single reference may have narrowed a participant's conceptualization of what constitutes a metallic sensation. It is also possible that some other sensations were mentally added into the metallic ratings in Experiment 1 due to the untrained naive subjects, a phenomenon commonly referred to as 'dumping'. However, the use of a number of taste and odor scales argues against this effect playing a major role.

Further work is warranted on this important conceptual issue. Methods from applied sensory evaluation may be able to tease apart the semantics used to describe sensations from copper and iron salts (Civille and Lawless, 1986). Descriptive analysis methods use trained panels to evaluate food products in applied sensory testing (see Lawless and Heymann, 1998). The training is based on the development of a consensus vocabulary and use of physical reference chemicals (examples) to provide phenomenological anchors for the sensation descriptors. A panel leader may act as a guide and assist in the procurement of reference materials, but the development of the descriptive terminology rests in the panelists, their deliberations/discussions and their selection of references. Careful development of a lexicon for a category of related sensations can shed light on the nature and extent of cues that subjects respond to when asked to rate the intensity of a particular sensation. This approach has proven useful in describing other complex sensory attributes. For example, terminology exploration for astringent sensations indicated that several sub-cues, such as drying, roughness and puckery/drawing sensations, can contribute to the overall impression (Lee and Lawless, 1991; Lawless and Corrigan, 1994). Green (1993) argued that these cues were one important piece of evidence that astringency was tactile and not gustatory in nature. A similar approach for metallic taste could clarify the nature, extent and overlap of metallic qualities.

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