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A Comparison of Two Electric Taste Stimulation Devices

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Abstract

Electrical stimulation of the tongue, commonly used in clinical evaluations of taste dysfunction, can produce a variety of sensations including reports of metallic taste. Two studies compared responses to a fabricated electrical stimulator (a 1.6 V battery, anode side exposed) and a clinical electrogustometer (Rion TR-06). Batteries placed on the anterior dorsal tongue surface produced sensations similar in intensity and quality to those produced by the clinical electrogustometer, with equal intensity on the tongue tip for the 1.6 V battery in the range of 33 – 56 μ A from the electrogustometer. A second study examined responses on three areas of the tongue on each side. Responses declined for areas lower in fungiform papillae for both devices, but at different rates. Higher current levels were required to match the battery in lower density areas, indicating spatial summation for the larger battery surface area. A consistent pattern of lateral differences was seen in only one subject. Quality descriptions were similar in frequency whether or not a word list was provided, with metallic, sour, pain and bitter being the most frequently mentioned words for both electric stimuli. Similarities in response to the battery device and electrogustometer were evident in intensity, qualities evoked, lack of a laterality effect and decreasing response in areas with lower fungiform papillae density. The battery device may provide an inexpensive portable alternative to an electrogustometer for use in clinical testing of taste.

Keywords

Electric taste; metallic taste; electrogustometry; laterality; taste quality

1. Introduction

Electrical stimulation of the gustatory nerves has been studied with a variety of devices [1–7]. Perhaps the most common electrogustometer in clinical practice is the Rion TR-6 [2, 8]. Recently, we developed an inexpensive hand-held device consisting of a watch battery (1.5 or 3 V, anode side exposed) affixed to a plastic handle, which could be used to stimulate different areas of the tongue [9]. This device was found to elicit metallic taste reports similar to those evoked by copper foil and copper/zinc bimetallic disks placed on the tongue, at higher rated intensities [9]. The device was also used in several multidimensional scaling

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experiments designed to look at the similarity of sensations from electric stimulation to those evoked by metal salts and traditional basic tastes [10]. There are several similarities between our device and the electrogustometer, such as the tendency to evoke metallic taste responses [9, 11] and more effective stimulation in areas high in fungiform papillae [9, 12]. However, there are also important differences in the physical setup and stimulus calibration.

The Rion electrode has diameter of 5.0 mm and a contact area of 19.6 mm². It provides anodal stimulation and the circuit is completed by a neck band with a gel pad. The battery has a diameter of 10.5 mm and a contact area of 86.6 mm². Most of the tongue contact is made with the central anodal surface of the battery but there is a small cathodal ring which extends to the anodal side, as shown in Figure 1. Thus the stimulation is effectively bipolar, with (negative ion) currents flowing from the anodal center outward. A third difference lies in the stimulus intensity specification. The electrogustometer output is calibrated in current flow in decibels, relative to a reference level of 8 μ amps, the approximate Japanese mean threshold, with each 20 db increase representing a 10-fold increase in current. In theory it should be possible to convert the voltage of the watch batteries to current flow by Ohm's law if the resistance of the tongue was known. However, given the differences in types and density of papillae on the tongue surface, the resistance is likely to vary. We thus attempted to cross-reference responses to the battery stimuli to responses from the electrogustometer by interpolating on psychophysical functions.

Several other comparisons were conducted as part of this study. Qualitative responses to the battery stimuli were compared to responses to the electrogustometer and to the existing clinical (normative) literature regarding the taste qualities evoked. This was done in both cued and uncued conditions as previous research indicated the nature and frequencies of quality responses could be affected by the categories offered to subjects [8, 9]. We also introduced the use of a discharged battery for comparison, to help control for the fact that the stimulus material, i.e. metal was obvious to the subjects and could provoke a response bias toward metallic taste reports. Another issue was the degree to which lateral differences in electric taste response might occur. Lateral differences are reported from chemical stimuli for only a minority of subjects [13–15], and differences in electrogustometer matching responses in one study are only in the range of 2 – 4 db [6]. Pilot work using the battery stimulus had suggested some side to side differences, so this issue was further examined in the second experiment.

Two experiments were conducted to compare responses to the battery stimuli and clinical electrogustometer. The goals of Experiment 1 were compare stimulation from a battery probe to that of the electrogustometer, establish a conversion from voltage to current in the tongue, and to compare the taste qualities reported. The goals of Experiment 2 were to look for laterality in taste sensitivity, to compare three areas of the anterior tongue differing in fungiform papillae density and to check for any bias in quality responses produced by not offering any list of descriptors to subjects. In our previous studies, the baseline or control stimulus was an inert Teflon disk attached to the plastic handle. A new control stimulus was introduced in these experiments, namely a discharged battery, which presumably would have more similar tactile and thermal conductivity properties to the fully charged battery.

2. Materials and Methods, Experiment 1

2.1 Subjects

Nineteen subjects (seven male, ages 18–55) were recruited from the Ithaca, NY area. The subjects had no training before being tested and were not informed as to the hypotheses of the study. Each subject gave informed consent before participating and received an incentive upon completion. All participants were in good health and reported no taste or smell problems. The The Cornell University Institutional Review Board reviewed and approved the study. Subjects received a token monetary incentive upon completion.

2.2 Stimuli

Battery probes were made by cutting the brush end off of a paint brush (length 115 mm, diameter 4 mm) at an angle and adhering the battery or Teflon disk to the end with “Super glue” gel. Radio Shack Watch and Calculator 357 Silver Oxide 1.5v batteries, both charged and discharged, and similar sized disks made from Teflon were used to make the probes. Paper clips were attached to the discharged batteries, making sure to touch both the positive and negative terminal, to keep the voltage as low as possible. Batteries were 99.75% discharged in approximately 5 days. The voltage was read shortly before usage of each battery probe and recorded. For the electrogustometer comparison, a TR-06 Rion Electrogustometer (Sensonic Inc., Haddonfield, NJ) was used. This provides anodal stimulation with a metal probe 5 mm in diameter with a grounding strap and gel pad on the neck to complete the circuit. Before testing, the probes were sterilized by dipping in 100% ethyl alcohol, followed by rinsing in deionized water and air-drying. A 0.1 M NaCl solution was made using deionized water and reagent grade NaCl to serve as the reference for magnitude estimation.

2.3 Procedure

A single session was conducted in the sensory evaluation facility in the Department of Food Science, Cornell University. After filling out a demographic information sheet and giving informed consent, subjects were instructed on the method of magnitude estimation, in which numerical ratings are made in proportion to the perceived intensity, relative to the perceived intensity of a reference standard (0.1 M NaCl, assigned the value “10”). Following the instructions, subjects filled out a practice magnitude estimation worksheet to check for understanding of the method.

Subjects rinsed their mouths with deionized water, then with 20mL of a 0.1 M NaCl solution (presented in pre-measured cups), then with deionized water again. Between each stimulus, subjects rinsed with deionized water. Between every three stimuli, subjects re-sampled the NaCl standard to refresh their memory as to what the “10” should be. After each stimulus, subjects rated the intensity and then gave verbal descriptors (such as salty or sour). A sheet with the following choices was available but subjects were not limited to these words: no taste, sweet, savory, metallic, bitter, irritating, salty, astringent, soapy, sour, rusty, pepper, fishy, tingle, sharp, spicy, broth-like and lemony. The experimenter recorded ratings and descriptors.

Subjects held out their moistened tongue and were informed immediately before either the left or right front anterior side of their tongue was to be touched with the probe (“I’m going to touch the right side of your tongue” *touch* “I’m going to touch the left side of your tongue” *touch*). The placement was in the most anterior position shown in Figure 3. The probe was held on the tongue for one second on each side. Each probe (Teflon, discharged battery, and live battery) was presented twice, in random order. Following the battery probes, the electrogustometer was used. Each current level (0db, 6db, 12db, 18db, and 24db) was presented twice, in random order. During the electrogustometer stimulation, the subject wore a grounding neckband to safely complete the circuit.

3. Results and Discussion, Experiment 1

Rated intensity increased with battery voltage and with electrogustometer current (battery series $F(2,38) = 89.03$, $p < .001$; current series $F(4,76) = 26.51$, $p < .001$). In the battery series, there was a significant stimulus by replicate interaction ($F(2,38) = 4.76$, $p = .015$), with response to the live battery increasing by about 15% in the second replicate (cause unknown). In the electrogustometer series, there was no significant difference between replicates or any interaction. Figure 2 shows sensation magnitude as a function of stimulus or current. The intensity of the 1.5V battery was converted to a current equivalent using this curve. The fully charged 1.5 volt battery, with an actual voltage of 1.61 V, produced a sensation equal to 17.0 db (56 μ a), with a 95% confidence interval between 13.5db (38 μ a) and 21.0 db (90 μ a). The “discharged” battery with a measured voltage of 0.0V was found to induce a non-zero rating, interpolated close to 0db (8 μ a, the normal threshold) on the electrogustometer scale. Individual transfer functions were also examined to interpolate battery responses on the electrogustometric psychophysical functions. The mean match to the 1.5V battery was 18.2 db (S.E. $\pm$ 2.2db) or 65 μ a, close to the value of 17 db obtained from interpolation on the group-averaged function.

The verbal descriptors were grouped by synonyms into six categories. For example, the category “pain” included other intense tactile words such as burning, irritating, sharp and tingle. Table 1 shows the response frequencies. There was no significant difference in the frequencies of responses to the battery stimuli and to the electrogustometer ($\chi^2(5) = 4.3$, $p = 0.5$). As current increased, the frequency of pain-related terms increased. Comparing the frequency of metallic and pain-related responses to the higher two levels (18 and 24 db combined) to the responses to the lower (6 and 12 db) levels, the pain responses increased (17% to 29%) while the metallic responses decreased (47% to 36%) ($\chi^2(1) = 3.88$, $p < 0.5$).

4. Materials and Methods, Experiment 2

Experiment 2 was conducted to examine three issues: whether responses to the battery device and electrogustometer would both change across tongue areas differing in fungiform papillae density, whether the frequency of responses would change as a function of an uncued condition (no list provided) and whether there were any consistent lateral differences in responses among subjects with either device.

4.1 Subjects

Eighteen new subjects (7 male, ages 18–55) were recruited from the Ithaca, NY area that had not participated in the first experiment. The subjects had no training before being tested and were not informed as to the hypotheses of the study. Each subject gave informed consent before participating and received an incentive upon completion. All participants were in good health and reported no taste or smell problems. The Cornell University Institutional Review Board reviewed and approved the procedure.

4.2 Stimuli

The stimuli in Experiment 2 were the same as those of Experiment 1 except that the 0.1 M NaCl solution, used as the reference standard, was replaced with a 6db stimulus from the electrogustometer as a standard, due to some reported difficulty by subjects in Exp.1 in comparing liquid to electrical stimuli. The standard was placed on the front of the tongue about 5 mm posterior to the “tip” position shown in Figure 3. Stimuli were delivered to the following tongue areas, as shown in Figure 3: the “tip” whose center point was approximately 7 mm from the midline on the front edge of the tongue, the “side”, center point about 25 mm posterior to the tip, on the edge of the tongue and the “back” about 15 mm from the midline and 50 mm from the tip. The “tip” position was approximately the same as in Experiment 1. Due to differences in the sizes of subject’s tongues, these positions are descriptive of the average size tongue positions. For all subjects, these positions were areas containing only fungiform and filiform papillae.

4.3 Procedure

Three sessions were conducted in the sensory evaluation facility in the Department of Food Science, Cornell University. After filling out a demographic information sheet and giving informed consent, subjects were trained in magnitude estimation, as in Experiment 1. Because of reports that it was difficult to compare a saline solution to an electric current, subjects were presented a 6db current from the electrogustometer, near the center of their tongue to avoid biasing a side or area. This served as the reference point of “10” for the other ratings. Subjects rinsed and were given the “10” again as in Experiment 1. After each stimulus, subjects were asked to rate the intensity of the sensation based on the reference and then give verbal descriptors as to the sensation they felt (without any prompting). The experimenter recorded ratings and descriptors.

Subjects were asked to hold out their moistened tongue and were informed immediately before one of six locations on the tongue was touched (back, side, and tip on both the left and right sides). The probe was held on the tongue for one second on each side. Each probe (Teflon, discharged battery, and live battery) was presented in random order. Each current level (0db, 6db, 12db, 18db, and 24db) was presented in random order. The procedure on each of the three sessions was the same, except for the order of probes, which was randomized.

5. Results and Discussion, Experiment 2

Mean responses for the electrogustometer and battery stimuli are shown in Figure 4. There were significant differences among areas and stimuli, and a significant stimulus by area interaction ($F(14, 238) = 9.36, p < .01$). The response intensity increases with electrogustometer current, but at a lower rate for the more posterior zones, consistent with others who found the tip of the tongue more sensitive to electric stimuli than other regions of the tongue [6, 9, 12, 16]. The battery stimuli, which were larger in contact area than the electrogustometer probe, showed less of a difference among areas. This difference is seen in terms of statistical overlap, examining the standard errors in Figures 4 vs. 5.

A smaller change across positions with the larger contact area of the battery led to an unexpected result in the intensity matches. A higher current match to the battery was required in areas of lower papillae density. Intensity interpolation of the 1.6 V battery responses on the current series gave equal intensity values of 12.2 db (32.6 μ a) for the tip of the tongue, 22.2 db (103 μ a) for the side and 25.7 db (154 μ a) for the most posterior zone. Individual transfer functions were also examined to interpolate battery responses on the electrogustometric psychophysical functions. The mean match to the battery was 12.2 db (S.E. ± 1.2 db) or 32.6 μ a, for the tip of the tongue, 22.7 db (S.E. ± 3.2 db) or 109 μ a for the side and 29.1 db (S.E. ± 4.0 db) or 227 μ a, for the posterior zone, close to the values interpolated from the group function. There was a significant area difference in matches calculated from the individual functions, with the tongue tip lower than the other two zones ($F(2,24) = 10.5, p < .001$ and Tukey HSD tests). The increasing matches for areas of lower responsiveness might be expected if the larger battery surface was recruiting more papillae and/or taste buds in the lower density areas. This result is consistent with area effects and spatial summation in the taste system [17].

To examine the issue of laterality, difference scores between left and right sides of the tongue on for each stimulus and each location on the tongue were graphed, after averaging over the three sessions. Data were visually inspected and sign tests were conducted to check for consistent patterns of lateral dominance. Only one subject showed a consistently stronger response on one side at $p < .05$ and four others at $p < .10$. Figure 5 shows the pattern for the one statistically significant subject (subject 20) and one subject representing the more common, apparently random, pattern.

Table 2 shows the distribution of verbal descriptors (for purposes of comparison to Exp. 1, on the responses to stimulation of the most anterior position or tongue tip are shown). There was a strong consistency from the cued condition in Experiment 1 to the uncued condition in Experiment 2, with the exception of lower frequency of “other” responses and higher frequency of “no sensation” responses in Exp. 2 ($\chi^2(5) = 69.2, p < .01$). The higher response of “no sensation” was expected in Experiment 2 based on the testing of areas of the tongue with lower fungiform papillae density and thus lower sensitivity. There was no significant difference in the overall frequency of the “metallic” choice ($\chi^2(1) = 3.09, p = .09$) in the two experiments. As in Experiment 1, there was a higher frequency of pain-related descriptors at the higher electrogustometer levels (13 to 18%), while metallic responses remained fairly constant (59 to 56%) ($\chi^2(1) = 3.87, p > .05$). Comparing the battery stimuli to the

electrogustometer, (Teflon omitted) there was now some difference, with a slightly higher response of bitter and “no sensation” to the battery than the electrogustometer, looking at only the tip of tongue responses ($\chi^2(5) = 19.2, p < .05$). However, comparing the 1.5V battery to its approximate intensity match (12 db), there was no significant difference in response frequency ($\chi^2(4) = 2.35, p > 0.5$).

6. General Discussion

The battery stimulus produced a pattern of response much like the clinical electrogustometer. This similarity is evident in the pattern of response that parallels fungiform papillae density, in laterality of responses, and in similar verbal quality identifications to those obtained by Tomita's group [6,10]. The stimulus provides a level of perceived intensity comparable to a range of 12 to 18 db on the electrogustometer scale. This suprathreshold level of stimulation may limit its use for detecting minor clinical losses of taste. However, unilateral anterior total loss of taste is associated with an increase of about 100 fold in current (the amount necessary to recruit trigeminal fibers on one side after chorda tympani transection), a difference that would be detectable with this device. Ajdukovic [3] remarked that a larger electrode was desirable in clinical testing to differentiate gustatory from somatosensory responses. The battery device delivers a current flow over a wider area and recruits more fungiform papillae and therefore more taste buds. Because both quality and intensity are comparable in the two devices, the battery device could prove useful in clinical testing. A validation could involve a series of partially depleted or lower voltage batteries, to see if the normal threshold value of 7 – 8 μ amps could be duplicated. Clinical comparisons with a population of individuals with known etiologies, such as unilateral chorda tympani transection, would also be useful. One limitation might be the need to check voltage before use in the clinic. However, the batteries have a shelf life of 3 – 4 years.

Another difference between the battery device and electrogustometer is the different size areas of contact with the tongue. The electrogustometer probe is a circle with an area of 20 mm², the battery probe is a circle with an area of 87 mm². In measurements of thresholds of electrical stimulation, a large change (factor of 32) in electrode area resulted in only a small change in threshold current (factor of 1.6) [6], although Miller et al. [16] found a four-fold change in area (12.5 to 50 mm²) to reduce threshold current density by about half. Furthermore, there is evidence of spatial summation [9, 17]. If spatial summation were occurring, then current per unit area necessary to produce a constant sensation would decrease [9]. However, the situation is further complicated by the fact that spatial summation may change with papillae density. Miller et al. [16] observed a steeper decline in thresholds as papillae density increased with a larger electrode, i.e. a more effective stimulus with a larger area (lower thresholds = higher potency). A parallel to this effect was seen here in the sense that the larger battery probe fell off less dramatically in areas with lower fungiform density, thus requiring a disproportionally higher match to the smaller the electrogustometer probe.

Previous examinations of the existence of side-to-side differences on the tongue have given mixed results. Lobb et al. [17] studied the reliability of electrogustometric thresholds in two

subjects over extensive repeated testing. Both subjects showed a consistent but small right side advantage (left side thresholds were higher). This result (a 1 or 2 μ amp difference was duplicated in a test of thresholds by Stillman et al. [7]. However, they noted, “although statistically significant, the right side advantage was small and unlikely to be clinically important.” Our findings of little or no consistent pattern for laterality are in agreement with Tomita et al. [6] who found a difference of only 2 – 4 db between the two sides of the tongue among normal subjects in a matching task. They concluded, “a sinistrodextral discrepancy of 6 db or more is indicative of a pathological condition” [6, p. 6].

At higher currents the stimuli produced more pain-related tactile sensations. This is consistent with previous findings that the perceived sensation moves from a taste to a more tactile or pain-related response as the electrical stimulus increases in intensity [4]. Once again, the modal response for electrical stimulation was metallic, in agreement with the normative data from the Japanese clinical group [10]. Use of a taste quality word list might bias subjects toward those examples [8,9]. However, the similar frequency of “metallic” choices in these two experiments suggests that the subjects were not biased by the appearance of the word in the list in Experiment 1. Whether this taste quality represents a mixture of other tastes or is a unique quality is still an unanswered issue. Tomita et al. [6] reported that the areas innervated by the chorda tympani were more likely to evoke a metallic response while more posterior oral areas were more likely to give rise to traditional chemical taste words. They concluded from this analysis of area and quality that metallic taste was a unique quality “different from the four primary tastes” [6, p. 11]. Note that the metallic taste from electrical stimulation is different from that induced by rinses with solutions of ferrous sulfate. The latter is inhibited by nasal closure (electric taste is not) and appears to be a retronasal smell evolving from a rapid lipid oxidation in the mouth catalyzed by ferrous ions [9, 19, 20].

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Figure 1.
Schematic of the battery stimulation device.

Figure 2.
Interpolation of battery intensity on standard curve for electrogustometer responses.

Figure 3.
Areas of lingual stimulation in Exp. 2 showing placement of stimuli on areas referred to in the text as tip, side and back.

Figure 4. Responses to electrogustometer, perceived intensity as a function of db and locus of stimulation. Refer to Figure 3 for positions.

Figure 5.
Responses to the 1.6 V battery, discharged battery and Teflon disk (control).

Figure 6. Laterality of responses to the one subject (upper panel, subject #20 in Exp. 2) who showed a consistent lateral differences and one subject (#14) showing a more typical random pattern.

Table 1

Frequencies of Descriptor Choices in Experiment 1

Descriptor	Battery stimuli	Electrogustometer
metallic	43 (39%)	118 (39%)
sour	15 (14%)	47 (16%)
bitter	4 (4%)	19 (6%)
pain	20 (18%)	61 (20%)
no sensation	10 (9%)	14 (5%)
other	17 (16%)	41 (14%)
total	109	300

Table 2

Frequencies of Descriptor Choices in Experiment 2 Anterior Tongue (“tip”) Only

Descriptor	Battery stimuli	Electrogustometer
metallic	114 (49%)	284 (47%)
sour	19 (8%)	86 (14%)
bitter	20 (9%)	37 (6%)
pain	19 (8%)	86 (14%)
no sensation	52 (23%)	86 (14%)
other	3 (1%)	23 (4%)
total	231	602