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A Taste Illusion: Taste Sensation Localized by Touch

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TODRANK, J. AND L. M. BARTOSHUK. *A taste illusion: Taste sensation localized by touch.* PHYSIOL BEHAV **50**(5) 1027–1031, 1991.—Taste sensations appear to come from all over the inner surface of the mouth, yet the taste receptors are restricted to relatively small particular areas of the oral surface. In addition, even if a relatively large (e.g., one half) proportion of the taste field is damaged, subjective taste experience may be unaffected. The touch system contributes to this constancy because taste sensations appear to be localized by touch. If a taste solution is painted from the side of the tongue (an area of low receptor density) past the tip (an area of high receptor density) and on to the second side, the taste sensation begins weak, gets stronger at the tip, and retains much of its intensity. The strong taste from the tip follows the tactile path of the stimulus sweep. This illusion occurs for all four stimuli tested: sucrose, sodium chloride, citric acid, and quinine hydrochloride.

Taste Gustation Illusion Touch Tactile Sucrose Sodium chloride Citric acid Quinine hydrochloride

THE perception of objects depends on sensory input from several sensory modalities. When the information from those modalities is in conflict, the resolution of that conflict leads to what may be called an illusion. Tastevin (22) coined the term "capture" to describe the dominance of vision over touch, and credited Aristotle (1) for the first observation of such an illusion. Hay, Pick and Ikeda (11) demonstrated visual capture using a prism that produced the perception of displacement of the hand: the hand was "felt" to be where it was seen. Shimojo (21) showed that when a finger was viewed through a prism such that two images were produced, moving eye fixation from one image to the other made the felt position move as well. Rock and Victor (20) had subjects view mounted objects through a lens while feeling them through a black cloth. The lens compressed the image of the object along the horizontal axis only. For example, the observer might be given a square to feel but see a rectangle standing on its shorter side. Vision predominated; the observers perceived the felt object as a rectangle. Only one in five observers was aware that there was a conflict.

Another example of sensory capture allows ventriloquists to appear to "throw" their voices and lets us perceive sounds as originating from their visual source in movies and television (14,15). This illusion is so powerful that seeing a face articulate "da" while hearing "ba" induces the perception of hearing "da."

Green showed that thermal localization can be influenced by touch (9). When the first and third fingers touch cold (or warm) stimulators and the second finger touches a thermally neutral (i.e., about body temperature) stimulator, the thermal sensations are referred to the middle finger and all three fingers perceive the stimulus as cold (or warm).

In the present paper, we suggest that another phenomenon can be added to those discussed above: taste sensations are not localized to the locations of taste buds, but rather to areas touched in the mouth. Thus, during eating, taste sensations seem to originate from the entire inner surface of the mouth even though the taste buds are found only on certain loci. Taste buds are found in three distinct types of papillae (fungiform, foliate, and circumvallate), which are visible on the tongue surface in the following actual locations. The fungiform papillae are visible as small reddened structures and are distributed on the anterior tongue with the greatest density at the tip (8). The foliate papillae are on the edges of the extreme back of the tongue. They can be visualized because the thinness of the skin makes

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the foliate papillae more red than nearby tissue (16). The circumvallate papillae are raised round structures laid out in an inverted V across the back of the tongue. In addition to the taste buds in the three types of papillae, there are taste buds on the roof of the mouth on the border between the hard and soft palates. Although taste receptors form a rough oval shape on the tongue and a line across the palate, we have no conscious awareness of this distribution.

Poor taste localization is also evident in cases of regional taste loss. Patients are usually unaware of oral areas that have been rendered insensitive to taste. For example, in 126 cases where the chorda tympani was severed unilaterally in the course of stapedectomy (6), 25 patients reported no taste symptoms. The remaining patients complained primarily of dryness of the mouth or the presence of a taste phantom (usually metallic). Seven patients noted that food had no taste until it reached the back of the mouth. In 32 patients where the chorda tympani was severed bilaterally, 7 noticed that food had no taste until it reached the back of the mouth. In one dramatic case (the same patient in whom we demonstrate the localization illusion in experiment two), the patient had no taste function on one side of his mouth and palate, but had no subjective awareness of any change in everyday taste experience (18,19).

The illusion under study here was first demonstrated by comparing taste solutions painted from the tip to the side of the tongue with those painted from the side to the tip (3). When the solution was painted from the side to the tip, it produced an increasingly strong taste with a maximum at the tip. However, when the solution was applied first to the tip of the tongue and then painted toward the side, the perceived intensity did not decrease symmetrically.

The technique developed for this study shows the illusion in a more efficient way: the solution was painted from one side across the tip to the other side (see Fig. 1). As the solution moved toward the tip, the taste intensity grew, but when the solution moved past the tip onto the second side, the intensity did not diminish to its original level. This procedure captures the baseline intensity and the illusion intensity within the same sweep. The rating for the first side and the rating for the tip provide the baseline for the perceived intensity at these two points, and the rating for the second side compared with the initial rating quantifies the illusion. Additionally, this technique adds robustness to the demonstration by challenging subjects to give magnitude estimation ratings that would contradict their probable expectation that they would taste a single solution applied to both sides of the tongue as being equally intense on each side.

The first experiment demonstrates this illusion with normal volunteers. The second experiment demonstrates the illusion in a subject with taste loss.

EXPERIMENT 1

Method

Thirty-eight subjects (22 females, 16 males) ranging in age from 18 to 40 were recruited from the Northeastern University community to participate in a study of taste perception. Some subjects received credit toward a course in Introductory Psychology. Each experimental session was conducted individually and lasted approximately 40 minutes.

Subjects rated tastes with the method of magnitude estimation (5). At the beginning of the session, subjects were trained in magnitude estimation by rating various distances indicated by the experimenter. They were instructed to use any numbers that seemed appropriate, with the restriction that a distance that was twice as great as another distance should get a number twice as large. After satisfactory performance on this task, the subjects were told to rate taste intensities in a similar way. In addition, the subjects were told that during each trial they should pay attention both to the particular taste quality, sweet, salty, sour, or bitter, and to the intensity of the sensation at three loci, first side, tip, and second side. Subjects were not told the purpose of the experiment.

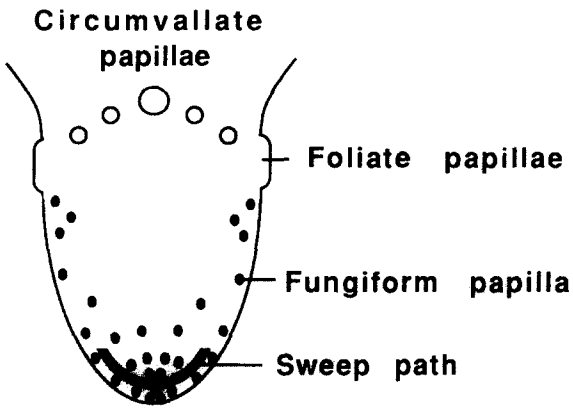


FIG. 1. The path of the Q-tip is indicated on the sketch above. Note that the sketch is merely intended to suggest the relative numbers of fungiform papillae on various tongue loci. Fungiform papillae are smaller and more numerous than shown in the sketch.

The stimuli were standard strong concentrations: 1.0 M sucrose, 1.0 M sodium chloride (NaCl), 0.032 M citric acid and 0.001 M quinine hydrochloride (QHCl). Subjects were asked to extend their tongues as far as was comfortable and to hold the tongue in place with the lips. Using a cotton-tipped applicator (i.e., a long-handled Q-tip), the experimenter applied each solution to the tongue in a sweeping movement beginning approximately one half inch from the midline on one side of the tongue, continuing past the tip, and ending on the opposite side at the point corresponding to the starting point on the first side (see Fig. 1). Each application was a smooth motion lasting just less than three seconds. The Q-tip was touched to the tongue and drawn along the surface. Equivalent pressure applied to a scale produced a pressure of approximately 11 grams. Subjects reported the taste quality and then the intensity estimates in order: first side, tip, second side.

The use of Q-tips to apply taste stimuli (2–4) is reminiscent of the use of paint brushes to apply taste stimuli in the 19th century (12). Q-tips offer important advantages in the modern era: they are sterile and can be discarded after a single use and so offer no risk to health. In addition, they are widely available in clinics and physician's offices and so can be used for clinical taste tests. Q-tips have the potential disadvantage of variation in the amount of solution held; however, within a particular brand the variation is small. Although visual inspection suggests that the Q-tips held ample taste solution to fill the area stimulated, if this ever failed to be the case, the illusion would have been less likely to occur. Since the purpose of this paper is to demonstrate the existence of the illusion, such an error would have simply served to make our task more difficult.

Each session had three blocks of eight trials. The direction (left-to-right or right-to-left) of the application and the taste stimulus were randomized in each block, except that the same taste stimulus was not presented twice in succession and the

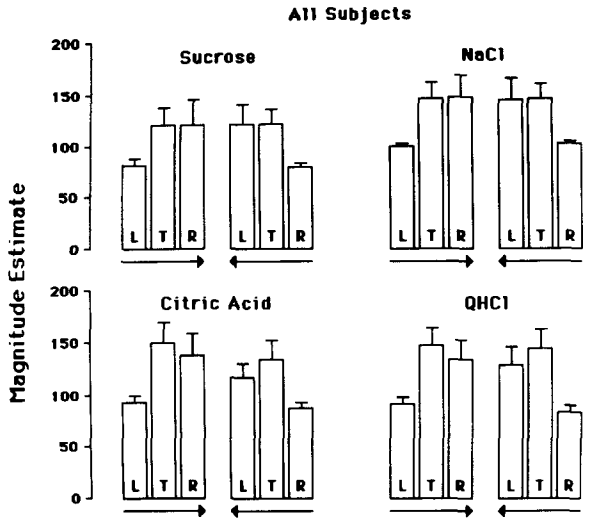


FIG. 2. Perceived intensities (±SE) measured with magnitude estimation of sucrose, sodium chloride (NaCl), citric acid, and quinine hydrochloride (QHCl) at three loci on sweeps from left to right and from right to left. Direction of sweep is indicated by the arrow under each set of three bars. The three loci are left (L), tip (T), and right (R) side of the tongue.

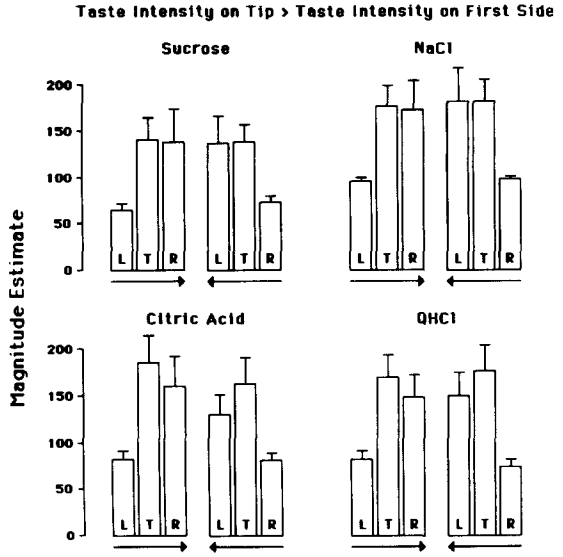


FIG. 3. Similar to Fig. 1. For each stimulus and sweep direction, subjects are shown who tasted the stimulus as more intense on the tip than on the first side. These subjects met the criterion for showing the illusion. Numbers of subjects for each sweep (left to right and right to left) were 25 and 27 for sucrose, 25 and 22 for NaCl, 24 and 24 for citric acid, and 27 and 24 for QHCl, resp.

same direction of application was not repeated more than twice in succession. Before each trial, the subject rinsed his/her mouth thoroughly with distilled water.

After all 24 trials were completed, the experimenter discussed the objective of the experiment with the subject and demonstrated the illusion.

Each subject's responses were averaged across the three blocks. All responses discussed below and shown in the figures are these averages (e.g., a sweep of NaCl from right to left is really the average of three runs of this condition). Each subject's averaged data were normalized by determining the average estimate of the perceived intensity of NaCl (ave N) on the first side of the two NaCl sweeps for each subject, and then calculating a normalization factor (NF) such that NF = 100/ave N. Each subject's data were multiplied by that subject's normalization factor. This procedure does not change the ratios among estimates, but does reduce variation due to differences in size of numbers used. NaCl was used since no zeros were given to judgments of NaCl on the first sides. Results were analyzed with ANOVAs. All multiple comparisons presented were a priori tests. Therefore, Newman-Keuls tests ($p<0.05$ or $p<0.01$) are reported regardless of whether or not the F was significant (7).

Results

Figure 2 shows the results for all subjects. The data were analyzed by a stimulus by locus (right or left) by order (first or second) ANOVA. The order effect was significant, $F(1,37) = 4.267$, $p<0.05$. That is, perceived intensity was greater on the second side than on the first side. Newman-Keuls tests showed that this effect occurred for each stimulus ($p<0.01$).

For each sweep, the illusion would not be expected to occur unless the perceived intensity on the tip was greater than that on the first side. For this reason, the results for each sweep were divided into two groups. For each stimulus and each direction, Fig. 3 shows subjects for whom taste was greater at the tip than the first side ("illusion possible" subjects) and Fig. 4 shows the results for subjects for whom the taste at the tip was less than or equal to the taste on the side ("illusion unlikely" subjects). For each stimulus and each sweep, a group (possible vs. unlikely) by order (first or second) ANOVA showed significant effects ($p<0.05$) only for the illusion possible subjects. This also shows that when the illusion is expected, it occurs for all four taste stimuli and both sweep directions.

In spite of these significant findings, inspection of the individual data indicates that the illusion did not occur for every

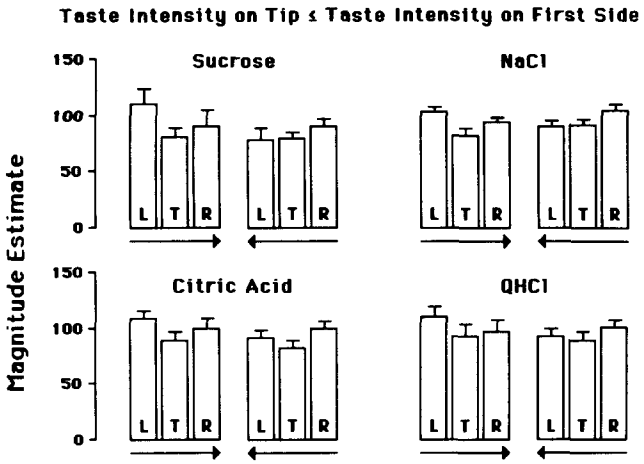


FIG. 4. Similar to Fig. 1. For each stimulus and sweep direction, subjects are shown who did not taste the stimulus as more intense on the tip than on the first side. These subjects did not meet the criterion and so were not expected to show the illusion. Numbers of subjects for each sweep (left to right and right to left) were 13 and 11 for sucrose, 13 and 16 for NaCl, 14 and 14 for citric acid, and 11 and 14 for QHCl, resp.

TABLE 1

(TIP − FIRST SIDE) VS. SIZE OF ILLUSION (SECOND SIDE − FIRST SIDE)

Stimulus	Direction of Sweep	Correlation Coefficient
Sucrose	R to L	.96
	L to R	.88
NaCl	R to L	.86
	L to R	.91
Citric Acid	R to L	.82
	L to R	.88
QHCl	R to L	.80
	L to R	.83

All of the correlation coefficients are significant ($p<0.001$). A Bonferoni correction for multiple tests requires p values of 0.006 to report the significance level to be $p=0.05$. Thus all of the correlation coefficients are significant with the Bonferoni correction (13).

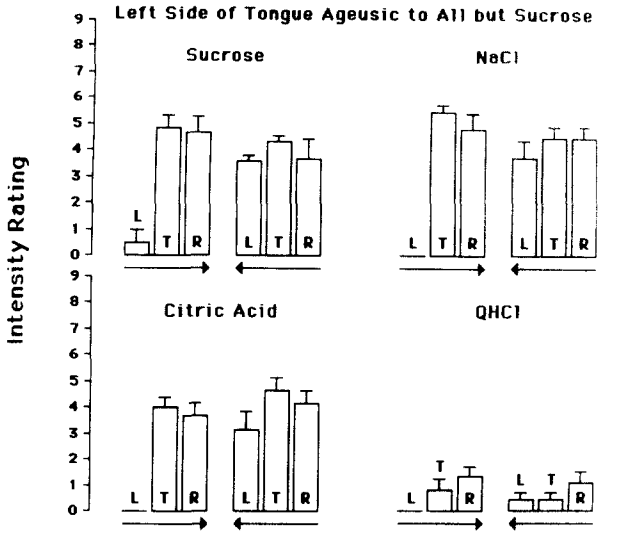


FIG. 5. Data for a subject with taste loss on the left side due to herpes zoster oticus. Similar to Fig. 1 except that intensity was judged on an intensity scale (±SE) such that 1 = very weak, 5 = medium, and 9 = very strong instead of with magnitude estimation.

subject. In addition, some subjects showed it only some of the time. Six subjects experienced the illusion on every sweep and ten never experienced it on any of the sweeps, even when it could have occurred. Three subjects never met the criterion of tasting the stimulus as more intense on the tip than on the first side of the tongue. The majority of the subjects (N = 19) perceived the illusion on some sweeps and not others.

Table 1 shows an association between the size of the illusion and the disparity between the tip and the first side of the sweep. Note that the correlations are high. The greater the taste intensity at the tip relative to the first side, the more intense the illusion (as measured by the difference between the two sides).

EXPERIMENT 2

Method

This experiment was conducted with a male subject (74 years old at the onset of the infection) who suffered from herpes zoster oticus (Ramsey-Hunt's syndrome), a recurrence of the virus that causes chicken pox in childhood (18,19). The virus damaged both the chorda tympani and the greater superficial petrosal branches of the facial (VIIth) nerve and the glossopharyngeal (IXth) nerve on the left side rendering the subject's tongue and palate completely insensitive to taste on the left side. At the time of testing for this illusion (more than a year after the beginning of the taste recovery), taste had partially returned to the field of the IXth nerve (rear of tongue) and to that of the greater superficial petrosal branch of the VIIth nerve (area between the hard and soft palates on the roof of the mouth). One area, the left front of the tongue, was still devoid of taste, except for a slight sensitivity to sweet stimuli. Both left and right sides of the front of the tongue were virtually insensitive to quinine.

The stimuli and the procedure were the same as in Experiment one with one exception. Intensities were judged on a 9 point scale such that 1 = very weak, 5 = medium, and 9 = very strong. Six runs of sweeps for all stimuli were conducted, two per day during three test sessions separated by approximately three weeks each.

Results

The results (shown in Fig. 5) were analyzed by a session by locus (right or left) by order (first or second) ANOVA. The six sessions were treated as independent. There was a significant stimulus by locus by order interaction, $F(3,15)=4.684$, $p<0.05$. Further tests showed that the illusion occurred for sucrose, NaCl, and citric acid, but not for quinine. Since the subject was essentially insensitive to quinine, no illusion was expected. The illusions shown for the other stimuli showed that the illusion will cross into an area that has been rendered devoid of taste through damage to the nerve.

DISCUSSION

In the present case, a moving touch stimulus (the Q-tip) draws the taste stimulus along its path, thereby referring the intensity from the tip into the less sensitive area on the second side.

Welch and Warren (23) concluded that ". . . intersensory bias is a result of an attempt by the perceptual system to maintain a perceptual experience consonant with a unitary event." The taste localization illusion insures that the taste of a substance is a unitary event and does not vary in intensity as the substance is moved throughout the mouth. This taste localization illusion also helps to explain why we are not aware of the location of taste receptors as part of everyday experience, and why patients who suffer localized taste losses often notice no change in taste experience.

When the illusion occurs on the normal tongue, we cannot conclude that it has crossed the midline since the strong intensity perceived at the tip of the second side could be responsible for the intensification on the second side. However, with the tongue that is ageusic to all but sweet on the left side, the intense taste at the tip on the right is drawn into the left side by the Q-tip creating a perception of taste in an area that has no taste function.

Experiments utilizing anesthesia of taste nerves contribute to an explanation of the stability of taste experience when part of the system is damaged. Neural responses in the rat medulla to stimulation of the posterior tongue increased when the taste nerve subserving the anterior tongue was anesthetized (10). The authors suggested that this was evidence for inhibition in taste. The chorda tympani and glossopharyngeal nerves project to spe-

cific areas in the central nervous system. These two areas appear to inhibit one another. Anesthesia of one nerve releases the inhibition that its central field normally exerts. This causes an increase in the neural responses from the other field. A similar experiment was conducted with human subjects (17). The subjects sipped solutions and then spit them out. One chorda tympani nerve was anesthetized with a standard mandibular block (like that used for dental work on lower teeth). Some of the solutions tasted more intense after the anesthesia. This release of inhibition helps maintain the constancy of taste intensity while the localization illusion makes taste seem to arise from all areas touched in the mouth and helps maintain the constancy of taste distribution. This combination of effects results in remarkably constant taste perception in the face of damage to the taste system.

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