Duplexity Theory of Taste

Abstract. *When two different taste stimuli are presented, one to the left and the other to the right side of the tongue, they may add together to a sensation in the middle of the tongue, or they may stay separated. This phenomenon can be used to show that the four primary taste sensations seem to form two well-differentiated groups. Warm and cold stimuli act similarly to the four primary taste stimuli, thus separating the sensations on the tongue into two groups: bitter, warm, sweet; and sour, cold, salty.*

The duplexity theory of the sense organs is about 100 years old. It was discovered in vision by three independent investigators, Schultze (*1*) in 1866, Parinaud (*2*) in 1881, and von Kries (*3*) in 1894. Duplexity seems to be common in the sense organs. In vision there are the rods and cones, in hearing the inner and outer hair cells; for equilibrium there are the statoliths and the semicircular canals, and the skin is sensitive to pressure and vibration in addition to cold and heat.

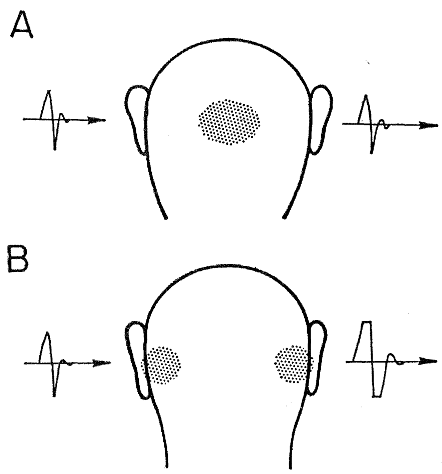

Fig. 1. (*A*) Two very similar clicks are presented simultaneously, one to each ear. If they are separately presented at equal loudness, they combine to a sound image midway between the two earphones. (*B*) If the clicks are very different, there is no interaction and they are heard separately in each ear. The sound images are represented by the shaded areas. The arrows represent time.

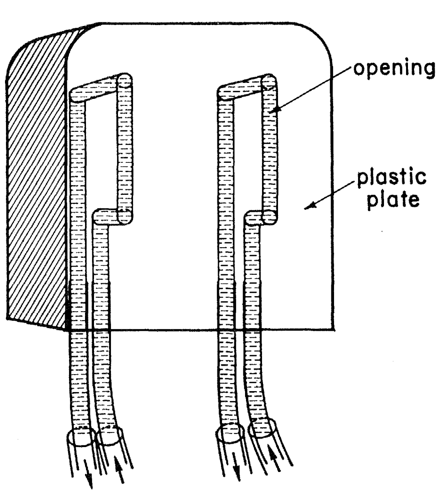

Fig. 2. Plastic block with two openings used to present two taste stimuli, one on each side of the tongue.

Besides the sensitivity to electrical and mechanical stimulation, the tongue is sensitive to the four primary tastes, bitter, sweet, sour, salty, and to heat and cold. Heat and cold may modify the taste sensations in accordance with the temperature coefficients of the four taste sensations. But there is also a strong possibility that heat and cold act as specific stimuli similar to the four taste stimuli and modify them by the process of summation or inhibition. Certainly inhibition can cause a greater change in a taste sensation than would follow from a change in the temperature coefficient. Therefore, by adding heat and cold to the four primary taste sensations, there are six sensations on the tongue, which may or may not interact among themselves to produce the final sensation.

This raises the question of whether these six sensations are equally independent of each other or whether they form into groups with some quality in common within the group. The existence of groups could provide some indications as to the directions in which further anatomical and physiological investigations should be made.

In my recent search for analogies between taste and smell on the one side and hearing on the other, several analogies have turned up. Directional hearing, for instance, finds its counterpart in taste (*4*) and in smell (*5*). It is possible to change the localization of a gustatory or olfactory sensation by stimulating two adjacent points on the tongue, or the two nostrils, with identical stimuli separated by a small time delay. The time delay necessary to move the sensation from one side to the other side is about the same as in directional hearing.

In directional hearing, localization can be used to place in rank order a series of different acoustical stimuli according to their similarity. When clicks of the same type are presented to the two ears separately but simultaneously, as in Fig. 1*A*, only a single click is heard. If the two clicks presented separately to the two ears are adjusted to equal loudness, the combined click appears in the medial plane of the head. If a positive or negative time delay is introduced, the sound image moves to one or the other side (*6*). If the click is distorted on one side by introducing nonlinear distortions by means of peak or center clipping, the clicks on the two sides still combine into a single click and appear in the medial plane of the head, provided the loudness of the two clicks presented separately are kept the same. The distortion can be increased to the point where the two clicks heard separately sound quite different, and still they interact with each other and form a common sound image. But if the distortion is further increased, a point can be reached where there is no longer any interaction, and the two clicks are always heard separately in the two ears, as indicated in Fig. 1*B*. In this way the breaking apart of the sound image into two separate sound images gives a certain measure of the common qualities of the two clicks. When the differences

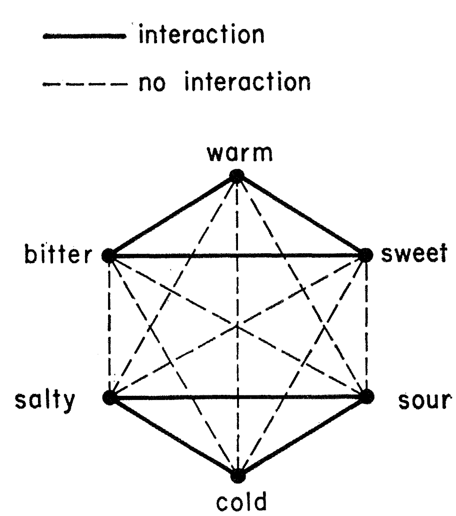

Fig. 3. The six different sensations which can be observed on the tongue. The stimuli that melt together to a common sensation, when presented simultaneously, are interconnected with solid lines, indicating that they have something in common with each other. Stimuli connected with dashed lines can be presented to the two sides of the tongue simultaneously without showing any interaction at all. This is the graphic representation of the duplexity theory of taste.

in their qualities become too great, there is no longer any interaction at all.

If the analogy holds between hearing and taste, it should be possible to repeat this experiment on the tongue and to find out whether there is any difference in the interaction between the four different primary taste qualities and the two added qualities of heat and cold. An experiment was therefore performed in which a lucite plate with two openings, as shown in Fig. 2, was placed on the surface of the tongue, with the openings on the left and right sides. The openings were 4 mm long, 1.5 mm wide, and 15 mm apart. Each was connected to a plastic tube, which provided a constant flow of water of about 36°C at about 1.5 ml/sec. A specially constructed electrodynamically driven valve (*4*) permitted the constant flow to be replaced by either a solution or by water of different temperature, at the same streaming velocity and without the introduction of additional changes. The solutions and the heated or cooled water were presented as stimuli to the tongue for 1 second. Each stimulus could be presented once, by the pressing of a button, or repeatedly every 10 seconds, according to the preference of the subject. A special arrangement permitted the concentration of the solutions to be controlled instantaneously over a range of 1 to 10 by the rotation of a dial. This was an important feature, because for good observations it was necessary to adjust the sensation magnitude so that it was equal on the two sides of the tongue. Care was taken to have the whole set-up for the two sides of the tongue equal, but since the sensitivity of the tongue for taste and temperature changes might be different on the two sides, the sensation magnitudes had to be matched before each observation.

Each session was begun by presenting single stimuli alternately to one and the other side and matching their sensation magnitudes. When the stimuli to the two sides are the same, this adjustment is not difficult; but when the stimuli on the two sides are different, for instance, bitter and heat, then the adjustment takes time and can be done only by approaching the mean adjustment by bracketing, from above and below. After the stimuli to the two sides were matched, they were presented to both sides "simultaneously," but with the means available to introduce a slight positive or negative time delay. The subject reported whether he localized a single sensation midway between the two openings or whether there were two separate sensations just below each opening. After a week of training in localization, both acoustical and gustatory, the subjects had no difficulty deciding whether there was interaction between the two sides or not.

When the same stimulus was presented on the two sides, the sensation was always localized in the middle, provided the sensation magnitudes had been matched. But when two different stimuli were presented to the two sides, there was sometimes an interaction and sometimes not. Bitter, warm, and sweet seemed to interact among themselves, and so did sour, cold, and salty. They seemed to form two clear groups of stimuli that had some quality in common. There was no interaction between the members of the two groups. We tried all 15 combinations of the four primary tastes plus heat and cold. We found it advantageous to use weak stimuli, since they gave a more definitive picture. This was especially true with cold, since for many observers cold may produce pain, which then inhibits interaction. Naturally, there is no single pure primary taste stimulus to be obtained. All the solutions used have some side tastes, more or less a combination of several primary tastes. Only heat and cold seem to be pure primary stimuli. In our experiments we used quinine for bitter, cane sugar for sweet, hydrochloric acid for sour, and sodium chloride for salt stimuli. Three well-trained subjects were used and for each of them the solutions were adjusted for their individual thresholds.

Our results are shown in a six-point scheme in Fig. 3 which shows clearly that the six primary stimuli fall into two well-separated groups, indicated by the two triangles.

Some experiments along different lines and which will be reported elsewhere (*7*) resulted in the same grouping, namely, bitter and sweet versus salty and sour. It will be of interest, therefore, to determine the anatomical and physiological correlates of this grouping.

Since the lateralization phenomenon has been helpful in the analysis of the grouping of taste sensations, it is hoped to apply a similar technique to olfaction. Presenting each nostril with a different odorant and observing its localization may lead to a division of olfactory stimuli into similar groups.

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References and Notes

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Depth Perception in Sheep: Effects of Interrupting the Mother-Neonate Bond

Abstract. *Twin lambs were divided into two groups: an unmothered group consisting of one of each pair of twins separated from its mother at birth, and a mothered group consisting of the other member of each pair reared by its mother. Lambs in both groups were placed individually on a "visual cliff" once every hour. In all instances lambs in the mothered group exhibited "cliff avoidance" behavior before those in the unmothered group. In another experiment, mothered lambs were fitted with translucent goggles for half the time required by unmothered lambs, matched on the basis of sex and birth weight, to acquire depth perception. Again, in all instances the mothered, goggled lambs avoided the cliff before the unmothered lambs.*

There is ample evidence (*1*) that interference with the formation of the mother-neonate bond in sheep and goats produces remarkable effects on later social and other behavior. Walk and Gibson (*2*) reported extensive use of a "visual cliff" in investigating the cues for depth perception, as well as the de-