The Effect of Adaptation on the Taste Threshold Observed with a Semiautomatic Gustometer

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ABSTRACT A special "gustometer" has been built, which permits continuous measurement of the threshold of taste sensations. Taste sensations show strong adaptation even at the threshold level. The adaptation was much the same for the four primary tastes, but there were large individual differences. Of theoretical interest is the finding that adaptation to a taste can occur even with subliminal stimuli.

INTRODUCTION

When a constant stimulus is switched on, the sensation requires a certain time—the onset time—to develop to its full magnitude. After this level is reached, the sensation begins to drop slowly and constantly in magnitude. This drop is called adaptation. It can be so pronounced that after a certain time the sensation completely disappears. There are instances in which taste shows this degree of adaptation. Dallenbach and Dallenbach (1943) used this phenomenon to measure adaptation. When the constant stimulus is switched off, adaptation may persist and leave the sense organ in a modified state: a second short constant stimulus may never reach the sensation magnitude of the first stimulus; its onset time may be very different; and the thresholds measured are much higher shortly after the first stimulus was switched off than before it was presented. The recovery from adaptation can take several minutes.

Adaptation of taste sensation has been investigated by Hahn (1934, 1936) who observed the changes in the threshold for a taste stimulus presented immediately after stimuli of different durations. The recovery from the adaptation was observed with additional test stimuli presented at intervals after the main stimulation was terminated.

In general, adaptation occurs with strong stimuli and decreases to zero as the sensation magnitude drops to the same value. As can be seen from Hahn's observations on taste (1949, Fig. 25, p. 189), the adaptation decreases linearly with the decrease in the concentration of the stimulus solution, and by extrapolation it would disappear at the threshold. Under these conditions it could be assumed that adaptation is closely related to the sensation magnitude or is even a function of it, so that we might say: no sensation, no adaptation. In this case we would probably choose to localize the process of adaptation in the nervous system.

On the other hand, we could assume that the loss of sensitivity during adaptation is due simply to some change in the end organ itself, and is completely independent of the activity of the nervous system and the firing of nervous discharges produced by the end organ. In this case, adaptation could occur at subliminal values of the stimulus. It would mean that, without having any sensations, we could adapt to them. The intensity range in which such a phenomenon could occur would naturally be very limited. It could not be observed in sense organs with very small adaptation, such as hearing, but there is a possibility that taste, with its large adaptation, could show the phenomenon of subliminal adaptation. Observations were made with a semiautomatic gustometer, working close to the threshold and avoiding as much as possible any stimulation of the taste sensation.

A subliminal threshold adaptation could have important consequences in daily life, since a very slowly rising stimulus could increase the threshold of the taste sensation considerably, without the situation being recognized. The thresholds for taste sensations differ considerably from observer to observer, but it is also probable that differences in the rate of adaptation may be even more evident in judgments of tastes.

SEMIAUTOMATIC GUSTOMETER

The underlying principle of the apparatus was the same as was previously used in the so called Békésy audiometer (Békésy, 1947). A subliminal stimulus is presented, and its intensity is continuously and slowly raised by a motor drive until the threshold is reached. At that moment, the motor drive is reversed by the observer, so that the intensity of the stimulus begins to drop below the threshold. When the observer is sure that he has no more sensation, the motor drive is again reversed and the stimulus is slowly increased again until it can be observed. The ups and downs of the stimulus intensity—between the value that produces a sensation and the value at which there is no sensation—are recorded on a graph, showing in detail the drift of the threshold with time.

The crucial component of the taste equipment is a device that varies the concentration of the test solution continuously and quantitatively, recording it at the same time. When a change in the concentration is required, it should be possible to carry it out immediately, so that the moment the observer is aware of the stimulus, any further increase in the concentration above the threshold is avoided. Several methods have been used for this purpose. The scheme shown in Fig. 1 has run smoothly for about 6 hours per day for several months.

The gustometer consists of two peristaltic pumps with soft latex tubing, connected as shown in the upper part of Fig. 1. The pump on the right side, with a rotation speed of n_1, moved an amount of the solution in the test tube presented to the tongue which was proportional to the speed. The speed of the pump could be increased or decreased by the observer in adjusting his threshold, and the speed was recorded automatically on a graph. The second pump n_2 mixed water into the solution in such

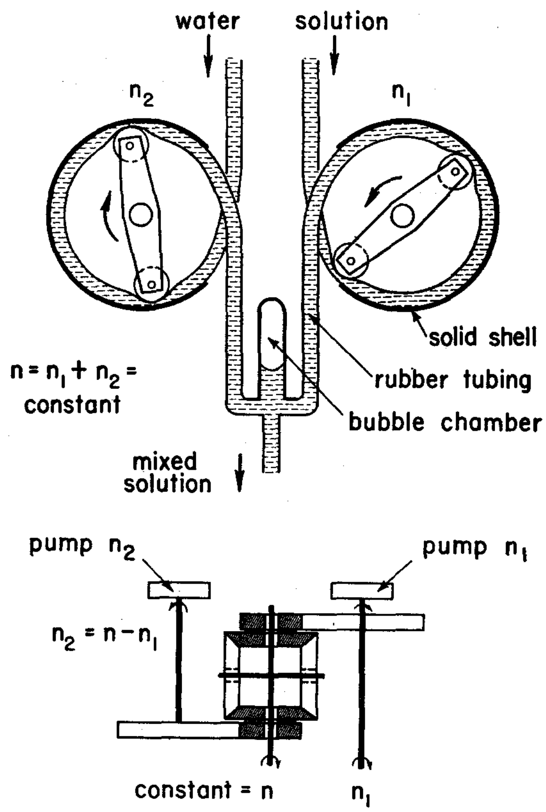

FIGURE 1. Differential pump permitting instant adjustment of the concentration of a solution to a predetermined value. Water and a standard solution are mixed to form the test solution. The concentration of the test solution is proportional to the speed of the peristaltic pump on the right side. The pump on the left side adds water to the standard solution so that the flow of the fluid mixture is independent of the speed of the pump n_1 on the right side. A differential gear, illustrated in the lower part of the figure, makes this adjustment. The test solution consists of pure water when pump n_1 is not operating, and it has the concentration of the standard solution when pump n_2 is not operating.

a way that the rate of flow of the mixture stayed constant; the sum $n_1 + n_2$ stayed constant during the changes in the concentration of the mixed solution. The correct speed of pump n_2 was produced by the differential gear shown at the bottom of the figure. The gear was driven by two motors, motor n_1 which was adjustable and determined the concentration of the solution in the mixed fluid, and motor n which determined the rate of flow of the mixed fluid. Motor n_1 was regulated by an electric speed control by means of a moving dial with the ratio of 1:10, which permitted the percentage of solution in the mixed fluid to be changed from 9 to 90 per cent. The length of the tube between the tongue and the interconnection of the two pumps was kept short, so that the time delay between setting the dial and the change in the fluid concentration could be kept to a minimum.

The fluid mixture was led through a plastic tube to a lucite block, shown in Fig.

2, with two openings, one on each side, which was placed on the surface of the tongue. Only one of the openings was used at any one time. The openings were placed laterally, since the sensitivity of the tongue is greater on the sides. The openings were 4 mm long, 1.5 mm wide, and 15 mm apart. The tube from the opening was made as short as possible and connected to a large tube into which the fluid dripped. This ensured that the fluid flow in the narrow tube would not produce on the surface of the tongue a DC pressure much above the atmospheric pressure. This arrangement helped to avoid leakage from the opening onto other places on the tongue.

The general assembly of the gustometer is shown in Fig. 3. At the extreme left is the motor which continuously changes the speed of pump n_1 and the concentration

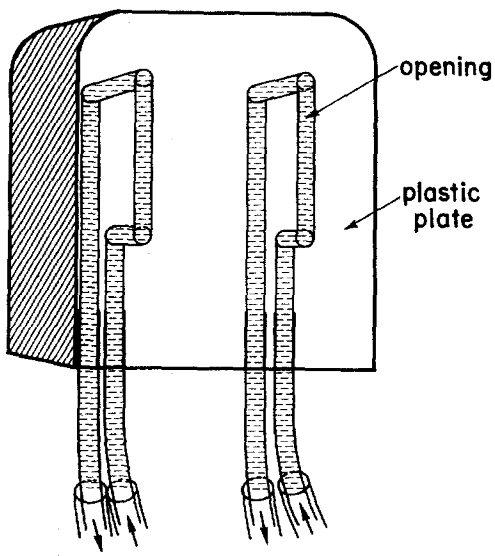

FIGURE 2. Lucite block with openings on the left and right sides through which the test solutions were presented to the surface of the tongue. Only one of the openings was used at one time. But it was possible to move the locus of stimulation from one side of the tongue to the other.

of the fluid mixture. The concentration is increased when the observer's switch is up and decreased when the switch is down. This slow motor is connected to the dial of the electrical speed control for pump n_1. By means of a chain belt and spring, the position of the dial is recorded on a graph as a function of time. The differential gearbox with the pumps is shown in the upper part of the drawing. The motor with the constant speed n is on the left side of the gearbox, but is not shown in the figure. The water (Cambridge tap water) and the solution were kept in large plastic bottles at room temperature. For most observers, different initial solutions were used, so that their threshold recordings would start at an appropriate position on the recorder.

Several facts limit the possible range of gustatory measurements. It is difficult to keep the mouth open for more than 5 minutes. If the room is dry, the surface of the exposed tongue dries out and produces wetting reflexes. It is convenient, therefore, to carry out the experiments in a humidified room. It is also difficult to keep the same spot on the tongue under the opening of the test tube for a long time. Since replacement of the stimulated area of the tongue with a new section acts as if a new measurement were being begun, the process of adaptation starts afresh and changes the form of the record. It is a common experience that, after about a 5 minute run of observations, the mouth should be closed and the tongue rested for about 15 minutes, to "dark-adapt" it, if an expression from vision may be permitted. A coffee break may change the threshold for taste more than is expected.

MEASUREMENT OF ADAPTATION AT THE THRESHOLD LEVEL

When we use the same semiautomatic method for the measurement of the auditory threshold of a 200 CPS tone, we obtain a recording of the type shown

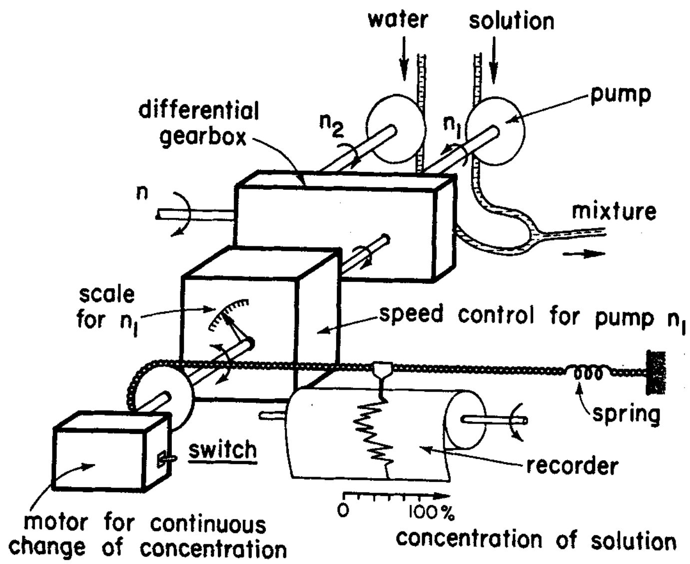

FIGURE 3. Semiautomatic gustometer. The concentration of the test solution is continuously increased until it reaches the threshold. At that moment the observer reverses the switch on the motor at the left side, which decreases the concentration continuously until no taste is experienced. Reversing the switch again increases the concentration until the threshold is again reached. This raising and lowering of the concentration near the threshold is repeated several times and recorded on graph paper.

in Fig. 4. The limits where the tone is just audible and just inaudible stay at the same sound pressures for 15 minutes or for even a longer period of observation. There is no observable adaptation in the hearing of a 200 CPS tone at the threshold level (Békésy, 1947). Adaptation occurs only at higher sound levels, which may be 100 to 10,000 times higher than the sound pressure level at threshold.

It is very different for observations of the taste threshold. In Fig. 5 are shown some typical recordings of taste thresholds. The initial concentration of a hydrochloric acid solution was adjusted so that, mixed with water to a 20 per cent solution, it just produced a taste at the beginning of the observations.

The initial concentration varied somewhat with the different observers; for each kilogram of water the average initial solutions contained 0.07 cc 40 per cent hydrochloric acid, 2.5 gm sodium salt, 7 mg crystallized quinine sulfate, and 3.5 gm cane sugar. The ordinate represents the percentage of the initial solution that was needed for threshold, and the abscissa represents time after

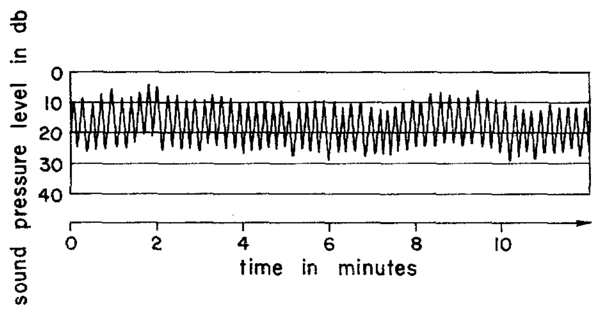

FIGURE 4. Auditory stimuli show no change in threshold value during prolonged observation. There is no adaptation near the threshold in hearing.

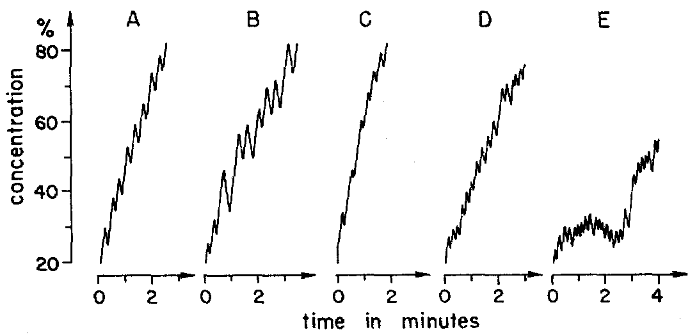

FIGURE 5. Threshold records for a hydrochloric acid solution show a constant rise in the threshold with presentation time of the stimulus. Records (*A*) and (*B*) show the repetition of the measurements by the same observer after a time interval of 2 hours; (*C*) and (*D*) are similar curves for a second and third observer; (*E*) represents the type of records obtained when the observer of record (*D*) moved his tongue during the time the record was being made.

the observations were begun. It is obvious from all these recordings that the threshold of the taste sensation rises continuously with the presentation time, even at threshold values. The records are quite consistent for the same observer. Figure 5 *B* shows a repetition of the observations of 5 *A* after an interval of 2 hours. The records show about the same slope for adaptation and the same concentration gap in the detection of the difference between the taste of the tap water and the taste of tap water combined with a clear taste of one of the other taste qualities. This gap can be considered a measure of the difference limen of taste sensation at the threshold level. The gap is strongly influenced by the training of the observer, but there are some physiological factors involved too, since after strong adaptation the difference limen may become much smaller than before for the same observer, and it can return to its original value after recovery of the taste sensation.

Figure 5 *C* shows the strongest adaptation we recorded, and at the same time the smallest difference limen for concentration changes. Records 5 *A* and 5 *C* represent about the extreme type for two different observers. Record 5 *D* is sort of medium one, showing that the speed of adaptation has a similar slope

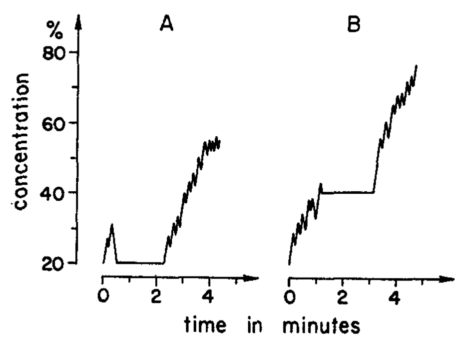

FIGURE 6. Evidence for subliminal adaptation. In record (*A*) after two threshold points the concentration of the test solution was decreased and kept constant 2 minutes. When the recording was started again, the first threshold points were at about the same values as before. In record (*B*), however, the concentration of the test solution was kept constant at a higher level for 2 minutes. During that period no taste was experienced. But adaptation still occurred, since, when the recording was started again, the first threshold points were almost as high as if the recording had gone on without interruption. In Fig. 6 *A* at the right end of the record, the adaptation process seems suddenly to stop, and the threshold remains constant. This is, in the opinion of the subjects, a consequence of the difficulty of keeping the tongue in the same position for more than 3 minutes. Any displacement of the tongue relative to the opening brings fresh unadapted areas into action and lowers the threshold.

and that adaptation produces a threshold shift to higher concentrations which is practically linear with presentation time. But all the regularities vanish when the tongue is moved during the observations, so that a spot on the tongue with no preliminary stimulation may start up the adaptation process anew. This is demonstrated in Fig. 5 *E*. In this case the observer did not know that he moved his tongue, but when it was done voluntarily similar records were obtained.

ADAPTATION BELOW THRESHOLD

The fact that adaptation is so easy to demonstrate near the threshold raises the theoretically important question of whether there is any adaptation below threshold. A simple way to test this possibility is shown in Fig. 6. Again an acid solution was used, and its initial concentration adjusted so that at the beginning of the record the threshold was obtained with 20 to 30 per cent initial concentration. As Fig. 6 *A* shows, the threshold observations were continued for about half a minute so that the initial threshold could be established. The concentration was then dropped to 20 per cent and kept there for 1½ minutes, after which threshold observations were started once again. The initial threshold observed immediately after this 1½ minute delay was not different from the threshold recorded at the beginning of the observations. This would seem to prove that exposing the tongue to the opening and to the flow of water does not affect the threshold, when the stimulus magnitude is kept far enough below the threshold. But if, after a few threshold points have been taken, the increase in concentration is stopped, so that the concentration stays constant for 2 minutes at the most recently observed threshold level, then the threshold will move to a higher concentration level (see Fig. 6 *B*). Apparently during the whole period in which the concentration of the stimulus was kept at a constant level just below the threshold, adaptation occurred in spite of the fact that no taste was observed. This seems to prove that there is adaptation, even during an interval in which no taste sensation was present. The phenomenon becomes especially clear when the constant concentration is presented at a level halfway between the upper and the lower levels of the last fluctuation in concentration (see Fig. 6 *B*).

Subliminal adaptation may play an important part in rapidly adapting sensations. It reminds me of an experiment that was carried out probably 100 years ago when the vacuum pump was new and exciting. When a rabbit was put under a vacuum bell and the air pressure was suddenly reduced, there was tremendous activity on the part of the rabbit, who was trying to get out. But when the air pressure was reduced very slowly, the rabbit could bleed to death without making any movement.

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