Magnitude estimations of the course of gustatory adaptation¹

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Magnitude estimations of 15-sec intervals were obtained during 2-min and 5-min adaptation of suprathreshold solutions of NaCl, quinine sulfate (QSO₄), and sucrose. Expectoring and adding fresh adapting solution at the end of each minute produced higher estimations than those obtained with continuous adaptation because of salivary dilution. Separation of the adaptation determinations by 45-sec rest intervals rather than 5 min had no effect on the form or magnitude of the functions for NaCl or sucrose, although QSO₄ adaptations separated by the shorter rest intervals were of greater magnitude. The absence of complete adaptation was largely attributed to the effects of tongue movements.

No direct psychophysical procedure has been used to study the course of gustatory adaptation. Prior work on gustatory adaptation has been mainly limited to studies of the effect of adaptation, especially NaCl adaptation, on the intensity or quality of other gustatory stimuli.

One indirect measure of gustatory adaptation which has been studied is the time required for complete adaptation, i.e., the disappearance of the sensation. Early work using the whole-mouth flow system known as the Cornell gustometer produced data on how long it took for solutions representing the four taste qualities to adapt (Abrahams, Krakauer, & Dallenbach, 1937; Krakauer & Dallenbach, 1937). NaCl solutions as high as 3.11 M and quinine hydrochloride (QHCl) solutions as high as 0.00083 M were reported to have adapted within 2 min, while suprathreshold solutions of sucrose and tartaric acid took longer. Similarly, Diamant, Oakley, Ström, Wells, and Zotterman (1965) reported that in humans 0.2 M NaCl completely adapted in under 2 min for both psychophysical tests on solutions held in the mouth, and electrophysiological recording of summated chorda tympani activity in response to the solution flowing over the tongue. Recent researchers concerned with gustatory adaptation have used dorsal tongue flow of from 15 sec to 2 min to produce adaptation (Bartoshuk, McBurney, & Pfaffmann, 1964; McBurney & Pfaffmann, 1963; McBurney, 1966; Bartoshuk, 1968).

Earlier work by Hahn and his colleagues (Hahn, 1934; Hahn, Kuckulies, & Taeger, 1938) indicated that functions of adaptation measured as the change in threshold over time were not of the same form for different compounds, although recovery from adaptation was. Neither Dallenbach and Dallenbach (1943) nor McBurney and Pfaffmann (1963) presented their threshold data as a function of time. The gustatory adaptation functions of four stimuli presented to a small area of the tongue were obtained by von Békésy (1965) using an apparatus similar to his audiometer. Unfortunately, he presented only the records for HCl.

The present experiment was undertaken to determine the form of the gustatory adaptation functions of sucrose, NaCl, and quinine sulfate (QSO₄) solutions by employing the method of magnitude estimation. The effects of varying the duration of adaptation, the intervals between successive adaptations, and the time that a solution was held in the mouth were investigated.

METHOD

Ss were four non-smoking female students at the University of Massachusetts, ages 17 to 22. These four were chosen from a larger group on the basis of their responses to a gustatory screening task previously described by Meiselman and Dzendolet (1967). All Ss had extensive experience in gustatory adaptation experiments involving quality responses and magnitude estimations.

The stimuli were 0.36 M NaCl, 0.000155 M quinine sulfate (QSO₄), and 0.35 M sucrose. The solutions were made with distilled water and reagent grade chemicals, except for ordinary table sugar. The three solutions had been judged to be of approximately equal sensory magnitude in an earlier experiment

using the same Ss. All solutions were maintained in a water bath at 35 deg during the experimental sessions.

The experiment involved four experimental sessions of 1 h each, with two sessions on each of two consecutive days. In each of the first three sessions, one solution was tested in the following manner. S was seated in front of a sink, asked to pour 10 ml of the solution into her mouth, and told to assign to this solution an initial sensory magnitude of the value of 10. At 15-sec intervals the experimenter signaled, and S rated the sensation magnitude of the solution, writing her estimation on a slip of paper. At the end of 1 min, S rated the solution as usual, then expectorated the solution, rated the magnitude of any taste remaining in her mouth, quickly took a second sample of 10 ml and rated it. After one more minute of 15-sec reports, S again expectorated, rating the solution just prior to and immediately after expectoration. There were 12 of these trials consisting of 2-min determinations. There were 5-min rest intervals between each of the first four trials, a 10-min interval between Trials 4 and 5, and 45-sec rest intervals between the remaining eight trials. S was instructed to assign a value of 10 only to the first sample of the first trial.

During the fourth session, each solution was tested under two conditions. The sensation magnitude of 10 ml of each of the three solutions was rated for 5 min at 15-sec intervals, keeping the same solution in the mouth for the entire time. Rest periods of 5 min separated the determinations for each compound. Finally, each of the solutions was again rated at 15-sec intervals for another 5 min, but this time S expectorated at the end of each minute and added 10 ml of fresh adapting solution. No magnitude estimations were required during the interval between solutions.

During all adaptations, S was asked to gently move her tongue, in order to attempt to expose all tongue surfaces and folds to the stimulus. Such a procedure was felt to be more advantageous than attempted stabilization of the tongue both because it more closely approximated the natural movements of the tongue during eating and because perfect stabilization of the tongue over long periods of time is difficult. Gentle tongue movements were considered to equate the condition of the four Ss more closely.

Because of space limitations in the water bath, all Ss received the stimulus solutions in the same order during each of the four sessions.

RESULTS

Mean magnitude estimations are presented in Figs. 1 and 2 for the 2-min adaptations with the 5-min rest periods and the 45-sec

Fig. 1. Mean magnitude estimations at 15-sec intervals (open circles) and at spits (closed circles) for 2 min of adaptation. Four consecutive 2-min adaptations are illustrated. The interval between adaptations was 5 min. The sensory magnitude of the first sample was assigned a value of 10.

Fig. 2. Mean magnitude estimations at 15-sec intervals (open circles) and at spits (closed circles) for 2 min of adaptation. Eight consecutive 2-min adaptations are illustrated. The interval between adaptations was 45 sec.

rest periods, respectively. Individual and group data indicated that in every instance the sensory magnitude of the solution decreased over the first minute, increased as the new solution was introduced at the end of the first minute, and then decreased again during the second minute of adaptation. Standard deviations for the above data have been presented by Meiselman (1968).

Certain points of the above adaptation functions were submitted to further inspection, to examine intertrial effects and compare interval effects: (a) the estimation given to the solution when first introduced (first initial estimate); (b) the estimation given to the second introduction of solution after 1 min (second initial estimate); (c) the estimation given at the end of 1 min (first final estimate); (d) the estimation given after the first expectation at the end of the first minute (first spit); and (e) the estimation given after the second expectation at the end of the second minute (second spit). Figures 3, 4, and 5 present the means of the four Ss for each of these measures for each stimulus.

Fig. 3. Mean magnitude estimations for measures of 2 min of adaptation for NaCl.

The second initial estimate functions were regularly below the first initial estimate functions for NaCl and sucrose, and for the 5-min interval function of QSO₄. The 45-sec interval functions of QSO₄ were higher in magnitude than those of NaCl or sucrose. The first and second final estimate functions for NaCl and sucrose were flat for both rest intervals and were of approximately magnitude 4. For QSO₄, this form and magnitude held for the 5-min rest periods, but after several trials separated by 45-sec rest periods there was a sharp increase in both first and second final estimates. Functions of the first and second spit estimates were slightly above the final estimates, and followed their general form. The curves were relatively flat for both NaCl and sucrose, while the functions for QSO₄ showed a sharp increase during the determinations separated by 45 sec.

Mean magnitude estimates of 5-min adaptations of NaCl, QSO₄, and sucrose are presented in Fig. 6. Standard deviations of these data were presented by Meiselman (1968). Under the continuous adaptation procedure, the mean sensory magnitude of all compounds declined from the initial value of 10 to a value of 1. Only one S reported that the quality of each of the three solutions completely disappeared during the 5-min session. These complete adaptations occurred in an average time of about 3 min. When these data are compared with the results of 5-min adaptation with expectation and addition of new solution at the end of each minute, the final levels of sensory magnitude reached for each of the three compounds were not as low as those reached with the continuous procedure. The estimations showed a decline during each minute, but with the exception of the first minute, never reached the lower levels attained with continuous adaptation.

DISCUSSION

Complete adaptation did not take place. The exception was for one S with continuous stimulation during which complete adaptation occurred in approximately 3 min. In view of prior findings of complete and relatively rapid adaptation (Abrahams, Krakauer, & Dallenbach, 1937; Krakauer & Dallenbach, 1937; McBurney, 1965; Bartoshuk, 1968), this finding deserves atten-

Fig. 4. Mean magnitude estimations for measures of 2 min of adaptation for QSO₄.

Fig. 5. Mean magnitude estimations for measures of 2 min of adaptation for sucrose.

tion. Several variables have contributed to this difference.

Abrahams et al (1937) suggested that constancy of the stimulus was a necessary condition for complete gustatory adaptation, and the Cornell gustometer assured an unchanging stimulus concentration. However, McBurney (1966) was unable to obtain complete adaptation even though assuring stimulus constancy through use of a dorsal tongue flow of NaCl, and Bartoshuk (1968) found instances of incomplete adaptation with 40 sec dorsal tongue flow of solutions of NaCl, sucrose, HCl and QHCl. The present study attempted to control for stimulus constancy by having Ss introduce fresh solution at the end of each minute. When such a procedure was not used, as with continuous 5-min adaptation, the magnitude estimations were considerably lower, as would be expected for a more dilute (less concentrated) stimulus. With regard to stimulus concentration, the Cornell studies cited above obtained complete adaptation in relatively short times to stimulus solutions considerably more concentrated than those used in the present study.

In earlier studies, Ss have been instructed to hold their tongues and cheeks immobile. Krakauer and Dallenbach (1937) showed that one S who was instructed to move his tongue showed longer adaptation times for tartaric acid, QHCl, and sucrose than other Ss. These results were attributed to the involvement of previously unexposed receptors. Békésy (1965) has shown that the typically smooth adaptation function obtained for a small area of the tongue is lost when the tongue is moved.

Dzendolet (1962) has suggested, based on data from electrical stimulation of single human papillae, that gustatory thresholds are a function of the rate at which ions are presented to the receptors. Continuous tongue movements would be expected to expose most if not all the receptors to a continuously moving stimulus. When a whole mouth flow system is used with the mouth kept immobile, not only are fewer receptors involved in the adaptation process, thus speeding it up, but also the stimulus solution is possibly being delivered to the receptors at a faster rate. When a dorsal tongue

flow system is used on the immobile tongue, even fewer receptors are available. Thus adaptation toward zero sensation magnitude, i.e., threshold, can be viewed in terms of the two variables, percentage of total receptors available and rate at which ions are presented to these receptors. The present method might maximize the percentage of receptors but minimize the rate of presentation of stimulating ions.

The presentation of certain characteristics of the 2-min adaptations in Figs. 3, 4, and 5 shows that when 5-min intervals were used between the 2-min determinations there were no large differences between the three compounds tested. When the interval between determinations was reduced from 5 min to 45 sec, responses to NaCl and sucrose showed little change from the pattern with 5-min intervals, while responses to QSO₄ were markedly affected. Repeated measurements of QSO₄ adaptation using relatively short intertrial intervals tended to exhibit a marked enhancement over measurements obtained with longer intervals. Further research is needed to determine whether the results for QSO₄ are indicative of other bitter compounds.

The increment in sensory magnitude observed with expectation supports the earlier and more qualitative observations of Abrahams et al (1937) and Krakauer and Dallenbach (1937) who attributed such an aftereffect to the involvement of previously unexposed receptors. Krakauer and Dallenbach found the longest aftereffect with QHCl. In the present study, the largest increase in sensory magnitude was also observed for the bitter stimulus. If the tongue were held rigidly during adaptation, expectation would be expected to expose more receptors than if the tongue had been moved during the entire procedure. Hence, earlier studies found that the stimulus solution returned from zero sensation magnitude, i.e., fully adapted, to full strength with expectation (Abrahams et al, 1937; Krakauer & Dallenbach, 1937), whereas less of an increment was observed in the present study.

The present experiment indicates that caution should be used in situations calling for repeated adaptations, such as threshold determinations following adaptation. The end points of such repeated determinations are to some degree dependent on the compound used and the interval separating determinations. Further, one cannot assume that the first adaptation produces the same degree of adaptation as the last in such a series.

The finding of similarly-shaped functions for the three compounds is in disagreement with the earlier results of Hahn (Hahn, 1934; Hahn, Kuckulies, & Taeger, 1938) who found differences among compounds in the form of adaptation functions based on repeated threshold determinations. Two factors can be suggested to account for this difference. First, the use of repeated measurements in adaptation is not an equally valid procedure for all compounds and for all intervals between repetitions, as

Fig. 6. Mean magnitude estimations at 15-sec intervals for 5 min of adaptation, either continuous (solid line) or with expectorating and addition of new solution at the end of each minute (hatched line).

discussed above. Secondly, comparisons of functions based on thresholds are not analogous to functions based on magnitude estimations. Such a situation is similar to that in cross-adaptation of salts, in which McBurney and Lucas (1966) have demonstrated that the threshold data and magnitude estimation data are not in agreement.

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NOTES

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