PREFERENCES OF THE WHITE RAT FOR SOLUTIONS OF SUCROSE AND QUININE HYDROCHLORIDE

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It was shown by Young and Christensen that hedonic processes summate algebraically when different concentrations of sucrose and sodium chloride are combined in a single compound solution.[1] The present investigation was undertaken to explore hedonic interactions in another area of gustatory stimulation. Compound solutions that contain both sucrose and quinine are ideal for the study of algebraic summation of hedonic processes because it is known that rats, when given a brief choice, prefer the higher sucrose concentration,[2] and that animals are aversive to solutions of quinine at most if not at all concentrations.

The present investigation is concerned with two main questions. First, what are the thresholds of aversion to solutions containing quinine hydrochloride when distilled water and different concentrations of sucrose serve as a base for threshold-determinations? Secondly, what concentration of quinine must be present to make a compound sucrose-quinine solution isohedonic to a standard sucrose solution of lower concentration? There is an incidental question: Are some quinine solutions preferred to distilled water?

METHOD

Apparatus. The apparatus used in this study has been described in detail elsewhere.[3] It consists of six boxes which can be used for testing six rats simultaneously. At the front of each box are two burettes with drinking spouts projecting through a lucite wall into the interior. When a rat touches its tongue to fluid at the tip of a nozzle, a circuit is closed through the floor of the box and the animal's body. A subthreshold current is amplified to operate relays and counters.

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* Received for publication September 29, 1962. The writers are indebted to Professor William E. Kappauf for valued assistance. The work was supported by Grant No. G-14538 from the National Science Foundation.

[1] P. T. Young and K. R. Christensen, Algebraic summation of hedonic processes, *J. comp. physiol. Psychol.*, 55, 1962, 332-336.

[2] P. T. Young and J. T. Greene, Quantity of food ingested as a measure of relative acceptability, *J. comp. physiol. Psychol.*, 46, 1953, 288-294.

[3] P. T. Young and W. E. Kappauf, Apparatus and procedures for studying taste-preferences in the white rat, this JOURNAL, 75, 1962, 482-484.

Procedure. In the present investigation, the same pair of test-fluids was presented in all six boxes of the electronic tester. Six rats were placed in the testing boxes successively at 10-sec. intervals, and 10 sec. after the last animal had been deposited *E* read the pair of counters for the first box. Every 10 sec. thereafter, he read a pair of counters for successive boxes in the row, thus obtaining one pair of readings per min. for each box throughout the exposure-period. At the close of a test, the animals were removed from the boxes in the original order at 10-sec. intervals. A record thus shows the cumulative number of tongue-contacts, minute by minute, for each animal, throughout a 15-min. exposure-period. With this procedure, it was possible to test six rats simultaneously in little more time than required for one.

At the start of the investigation, we ran two tests for each pair of fluids—one test per day with burettes in each spatial order. Later we found it feasible to reverse positions between successive daily tests while steadily increasing the concentration of quinine.

Effects due to order of presentation are difficult to control in work with quinine solutions because the higher concentrations markedly inhibit the animals and may give a persistent aversion to both test fluids. After preliminary observations, we decided to work only with ascending series of quinine concentrations and not to exceed a concentration of 0.25 gm./100 ml. solution.

Solutions. Solutions were prepared and specified as weight/volume ratios. In simple solutions, the concentration is expressed as the number of grams of solute dissolved in 100 ml. of solution and in compound solutions the concentrations of two solutes, sucrose and quinine, are expressed as grams per 100 ml. of solution. In earlier work such weight/volume ratios were called *percentages* but this is a misnomer.[4]

All solutions were prepared with distilled water. For sucrose, we used a good quality of commercial cane sugar. Chemically, sucrose is $C_{12}H_{22}O_{11}$ and its molecular weight is 342.3. For simplicity, we refer to sucrose as *CHO*. Chemically pure quinine hydrochloride crystals were used. Chemically, quinine hydrochloride is $C_{22}H_{24}O_2N_2$. HCl and its molecular weight (anhydrous) is 360.88. For simplicity, we refer to quinine hydrochloride as *Q*.

[4] In papers published by P. T. Young, 1944-1949 inclusive, *molal* concentrations were used, *i.e.* a 1% solution was 1 gram of solute added to 100 cc. of distilled water. Subsequently, beginning with the study by Young and Greene (*op. cit.*) in 1953, and terminating with a study by Young and Christensen (*op. cit.*), solutions were prepared and specified in terms of a true percentage by weight. This method of specification was used because of an interest, at the start, in the quantities of solute and solvent ingested; and we measured intake consistently in grams. In all current studies upon preference and activity, carried out with the electronic tester, we have prepared and specified solutions as weight/volume ratios and measured intake in volumetric units. A weight/volume ratio has several advantages: (1) it is readily understood and meaningful to nonchemists; (2) it is convenient in preparation of simple and compound solutions by dilution; and (3) specifications of concentrations as weight/volume ratios can be transformed readily to molar concentrations when the molecular weight of the solute or solutes is known. On the problem of preparing and specifying solutions see: Carl Pfaffmann, P. T. Young, V. G. Dethier, C. P. Richter, and E. Stellar, The preparation of solutions for research in chemoreception and food acceptance, *J. comp. physiol. Psychol.,* 47, 1954, 93-96.

All solutions containing Q were prepared by dilution from a stock of 1 gm./100 ml. solution. In the total experiment, we used 15 concentrations of Q. The highest concentration (Q_{15}) was 0.25 gm./100 ml. solution; the next (Q_{14}) was 0.125 gm./100 ml. solution; and so on down, each concentration being one-half of the preceding concentration. The Q-scale is shown at the base of Fig. 1.

Rats and diet. The Ss were female rats, 50-60 days old at the start of the experiment and less than 1 yr. old at the close. They were received from the Holtzman Rat Company in three shipments.

The rats were fed *ad libitum* upon an unlimited supply of Purina rodent cubes and tap water. There was no dietary depletion, deprivation, or metabolic need at any time as far as we know. The animals were taken directly from their living cages to the testing apparatus. They were need-free. Need-free rats, of course, are not the same as satiated rats; a need-free animal may or may not be satiated upon a test-fluid such as a sucrose solution.

RESULTS

In analyzing the data, we relied upon two main methods. First, using the individual rat as a unit, we tabulated the numbers of animals within a group showing preference for one fluid and for the other. Secondly, for each individual rat we examined the absolute and relative frequencies of tongue-contacts with each test-fluid. The fluid receiving the greater number of tongue-contacts during a specified exposure-period was arbitrarily defined as the preferred fluid.

(1) *Aversion-thresholds: Quinine vs. distilled water.* In the first series of tests, 12 rats were offered a choice between distilled water and a solution of quinine hydrochloride. The series began with the lowest concentration, Q_1, and continued step by step to the highest, Q_{15}. Each quinine solution was paired with distilled water and a pair of test-fluids was presented for 30 min. with one spatial arrangement of burettes and on the following day for 30 min. with the reverse spatial arrangement. Each two-day test was scored as a unit, the fluid with the greater number of tongue-contacts being counted as the preferred fluid.

During the first six tests, Q_1 to Q_6, there was no significant preference for either fluid. At no concentration was the quinine solution preferred to distilled water. With concentrations Q_7 to Q_{15}, more rats showed a preference for water than for quinine, but the animals became increasingly inactive as the concentration rose.

Individual aversion-thresholds were determined. An aversion-threshold is defined as that concentration of quinine at which 25% of the tongue-contacts are with the quinine solution and 75% with distilled water. For purposes of the study, we discarded tests in which an individual rat made fewer than 100 contacts during a 2-day 60-min. test. With this criterion, we had to eliminate two rats which simply became inactive before meeting the criterion of aversion. The remaining ten rats showed aversion-thresholds between two quinine concentrations as follows:

Concentration of *Q*:	6		7		8		9		10		11		12		13		14		15
Number of rats:		1				2		2		2		1		1		1			

The range of these thresholds is from $Q_{6.5}$ to $Q_{13.5}$ or from 0.0007 to 0.094, and the mean is 0.0086 gm./100 ml. solution. This range and the mean are shown at the top of Fig. 1.

There was a marked tendency for the frequency of tongue-contacts to

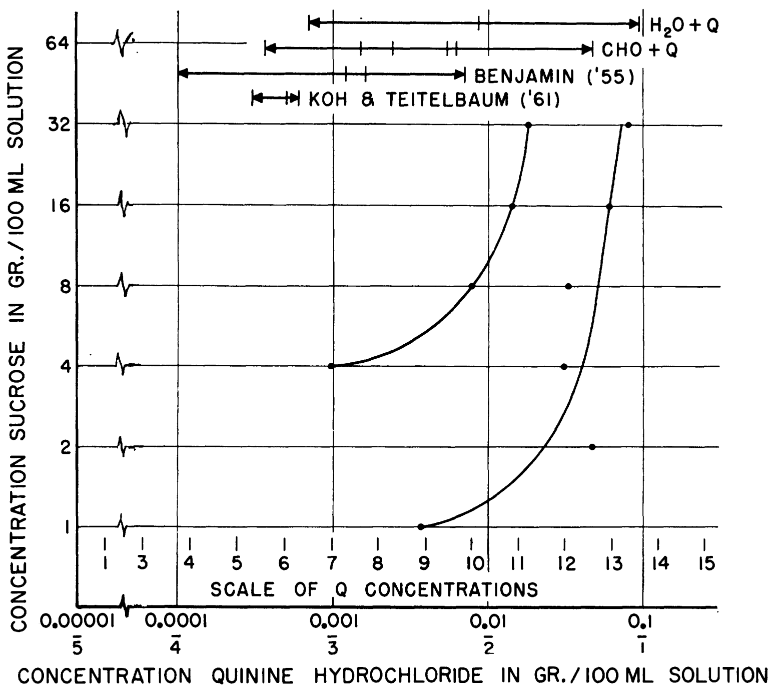

FIG. 1. AVERSION-THRESHOLDS AND ISOHEDONS IN THE SUCROSE-QUININE HYDROCHLORIDE AREA

decrease with increasing concentration of *Q*. This decrease was present with *both* fluids, but from Q_7 to Q_{15} there were consistently and significantly more contacts with water than with quinine solution.

(2) *Aversion-thresholds: Quinine vs. sucrose.* Following the above

tests with distilled water, four series of tests were made in which a simple sucrose solution was pitted against a compound solution containing the same concentration of sucrose and an ascending series of quinine concentrations. The four series were 1 *CHO* vs. 1 *CHO* + *Q*; 2 *CHO* vs. 2 *CHO* + *Q*; 4 *CHO* vs. 4 *CHO* + *Q*; 8 *CHO* vs. 8 *CHO* + *Q*. A complete preference-test required two days, since both spatial arrangements of the burettes were presented. In these and all following tests the exposure-period was reduced to 15 min./day. The first two series of tests were run with 24 rats, tested in groups of 6. Then the group was divided and the last two series were run on the same days with 12 rats in each subgroup. Each 2-day test was scored in terms of the numbers of tongue-contacts

TABLE I

NUMBER OF RATS SHOWING PREFERENCE FOR SUCROSE AND FOR SUCROSE-QUININE SOLUTIONS AT DIFFERENT LEVELS OF CONCENTRATION

N	Solutions tested	Concentration of *Q* in Compound solution														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
24	1 *CHO*						15	20	21	23	21	22	24	24	24	24
	1 *CHO*+*Q*						9	4	3	1	3	2	0	0	0	0
24	2 *CHO*	19	19	22	15	16	20	21	23	24	23	24	24	24	24	24
	2 *CHO*+*Q*	5	5	2	9	8	4	3	1	0	1	0	0	0	0	0
12	4 *CHO*	9	7	5	7	7	7	9	11	10	12	12	12	12	12	12
	4 *CHO*+*Q*	3	5	7	5	5	5	3	1	2	0	0	0	0	0	0
12	8 *CHO*	5	7	5	6	3	7	9	8	7	10	12	12	12	12	12
	8 *CHO*+*Q*	7	5	7	6	9	5	3	4	5	2	0	0	0	0	0

during the 30-min. exposure-period, the fluid receiving the greater number of contacts being scored as the preferred fluid.

Table I shows the number of rats with a preference for the simple *CHO* solution and for the paired compound *CHO* + *Q*. In the first series of tests, we omitted the lower concentrations of *Q* and began with Q_6, but in the other series all 15 concentrations of *Q* were presented in ascending order.

From the data recorded in Table I, we determined aversion-thresholds for the group as a whole. An aversion-threshold for the group is defined as that concentration of *Q* at which 25% of the rats prefer *CHO* + *Q* and 75% prefer *CHO*. Aversion-thresholds were determined from group-data graphically, by linear interpolation. The values obtained are shown in Table II.

Since the group-data do not reveal individual differences, we determined an aversion-threshold for each rat in each series of tests, relying upon the relative frequencies of tongue-contacts. The individual threshold usually fell between two *Q*-values; we then placed the threshold at the mid-concentration.

Table II shows the range of individual aversion-thresholds and the mean of individual thresholds at four levels of *CHO*-concentration. The total range of individual aversion-thresholds and the four mean values

TABLE II

AVERSION-THRESHOLDS BASED ON DATA FOR GROUP AND FOR INDIVIDUAL RATS

Test	*N*	Group-data	Individual data	
			range	*M*
1 *CHO* vs. 1 *CHO+Q*	24	0.00078	0.00073–0.0470	0.0054
2 *CHO* vs. 2 *CHO+Q*	24	0.00036	0.00036–0.0120	0.0015
4 *CHO* vs. 4 *CHO+Q*	12	0.00073	0.00073–0.0059	0.0024
8 *CHO* vs. 8 *CHO+Q*	12	0.0052	0.00150–0.0230	0.0062

are presented graphically near the top of Fig. 1. The data in Table II indicate that group-thresholds, based upon the frequency of preferences within a group, are lower at each *CHO*-level than the mean individual thresholds, based upon tongue-contacts. All aversion-threshold values, however, are of the same order of magnitude.

(3) *Tests with sucrose.* After the above studies of aversion-thresholds, we turned to the problem of reversing preferences by adding quinine to an an originally preferred sucrose solution. The general plan was to establish a preference between two simple sucrose solutions, and then to add quinine hydrochloride to the preferred fluid, step by step, until the preference reversed. The preliminary tests with simple sucrose solutions revealed some interesting results which will be briefly considered before we turn to the effects of adding quinine.

In the preliminary tests with sucrose solutions, all rats without exception developed a preference for the solution with the higher concentration, which result agrees with theoretical expectation.[5] The rate at which a preferential discrimination developed was a function of the difference in concentrations between the two sucrose solutions. When the difference between two concentrations was small, the animals apparently could and did learn to discriminate preferentially between the test-fluids; but, when the difference was large, the animals almost immediately showed a preference for the higher concentration.

[5] Young and Greene, *op. cit.,* 288-294.

In the preference test with 2 *CHO* vs. 1 *CHO,* the difference in concentration was small. Table III shows the development of a preference (referred to as a preferential trend) in this test. The table gives the number of rats, in a group of 24, with a preference for 2 *CHO* and the number with a preference for 1 *CHO.* It will be seen that repetition of this test yielded increasing frequencies of preference for the fluid with the higher concentration.

After 10 initial tests with simple *CHO*-solutions, we added the lowest concentration of quinine, Q_1, to 2 *CHO.* The test with 2 $CHO + Q_1$ vs. 1 *CHO* was made with all 24 rats; apparently the addition of Q_1 made no difference in the preference for the fluid containing 2 *CHO.* Then, with

TABLE III

Preferential Trend with Two Sucrose Solutions (24 rats) and Reversal of Preference with the Addition of Quinine to the Preferred Solution (12 rats)

No. rats with a pref. for:	Preference test: 2 *CHO* vs. 1 *CHO*										2 $CHO+Q_1$ vs. 1 *CHO*	
2 *CHO*	13	16	19	18	18	21	23	20	24	19	24	23
1 *CHO*	11	8	5	6	6	3	1	4	0	5	0	1

No. rats with a pref. for:	Concentration of Q in 2 $CHO+Q$ vs. 1 *CHO*: 2	3	4	5	6	7	8	9	10	11	12	13	14	15
2 $CHO+Q$	12	11	12	12	12	12	12	11	11	9	7	5	3	0
1 *CHO*	0	1	0	0	0	0	0	1	1	3	5	7	9	12

12 of the rats, the concentration of Q was increased gradually, as shown in Table III. From Q_1 to Q_8, the addition of Q made no difference in the preference for the fluid containing the higher *CHO*-concentration. In fact, the preferential trend continued until all rats consistently preferred the fluid containing 2 *CHO.*

In other tests with larger differences in sucrose concentration, the preferential trends were present but less pronounced. This fact is illustrated by results recorded in Table IV.

In the tests with 32 *CHO* vs. 1 *CHO* and 16 *CHO* vs. 1 *CHO,* a preference for the higher concentration of *CHO* appeared immediately, and repetition of these tests was not necessary; but, in the tests with 4 *CHO* as a standard, three or four daily repetitions were required to establish uniformity of preference for the sucrose solution with higher concentration.

Another interesting result came to light when we made a minute-by-minute analysis of the test with 32 *CHO* vs. 1 *CHO.* The data-sheets revealed that after the first 2 min. there was a steady decline in the drinking of 32 *CHO.* During the last 6 min., the rats were almost completely inactive, making no contact with either fluid. This pattern of behavior marks the approach to satiation upon a highly concentrated sucrose solution.

During the approach to satiation, some rats made 1 or 2 or 3 contacts with 1 *CHO* in an otherwise inactive minute. Some animals, as they approached satiation, tasted first one and then the other fluid—a pattern of behavior which was observed also during the first minutes of testing. Such sampling of the fluids appears to be of an exploratory nature and not a true indication of preference.

TABLE IV

PREFERENTIAL TRENDS WITH PAIRS OF SUCROSE SOLUTIONS AND REVERSALS OF PREFERENCES WITH THE ADDITION OF QUININE TO THE PREFERRED SOLUTIONS
($N=24$ rats)

No. of rats showing preferences

Solutions	Tests without *Q*				Concentration of *Q* added to higher concentration of *CHO*								
					7	8	9	10	11	12	13	14	15
4 *CHO*	22	23	24	24	22	23	24	22	20	11	6	2	2
1 *CHO*	2	1	0	0	2	1	0	2	4	13	18	22	22
8 *CHO*	18	23	23	24		24	24	23	19	8	4	1	2
1 *CHO*	6	1	1	0		0	0	1	5	16	20	23	22
16 *CHO*	23	24	24	24		24	24	24	24	20	12	3	2
1 *CHO*	1	0	0	0		0	0	0	0	4	12	21	22
32 *CHO*	24	24	24	24		24	24	24	24	23	16	3	1
1 *CHO*	0	0	0	0		0	0	0	0	1	8	21	23
8 *CHO*	19	23	24	24		18	18	11	6	2	1	0	0
4 *CHO*	5	1	0	0		6	6	13	18	22	23	24	24
16 *CHO*	20	21	24	24		22	21	19	11	3	0	0	0
4 *CHO*	4	3	0	0		2	3	5	13	21	24	24	24
32 *CHO*	22	20	23	24		21	21	16	14	3	1	0	0
4 *CHO*	2	4	1	0		3	3	8	10	21	23	24	24

In at least one-fourth of the available records, however, rats turned to 1 *CHO after* they had ingested considerable quantities of 32 *CHO* and continued drinking 1 *CHO* until they became inactive. This pattern of behavior suggests that, as rats approach satiation on 32 *CHO,* some of them express a transient preference for a fluid containing less *CHO* and more water. The transient preference is a half-way station on the road to satiation.

(4) *Reversal of preference.* The results summarized in Tables III and

IV show that a preference for the higher concentration of sucrose can be reversed by adding quinine to the preferred fluid. From the data it is possible to determine how much *Q* must be added to a preferred *CHO*-solution to make the compound isohedonic to a simple *CHO*-solution of lower concentration. For a group of rats, the isohedonic concentration is defined as that concentration of *Q* at which half of the animals prefer *CHO* + *Q* and half prefer a simple *CHO*-solution of lower concentration.

The exact location of isohedonic concentrations was determined graphically, by linear interpolation, from the data in Tables III and IV. Similarly, isohedonic concentrations were determined from the data in Table I. Results were read from right to left until the highest isohedonic values

TABLE V

ISOHEDONIC CONCENRTATIONS BASED UPON GROUP- AND INDIVIDUAL DATA

Preference test	Group	Individual rats		
		Range	*M*	*N*
1 *CHO* vs. 1 *CHO*+*Q*	<0.00049	0.00024–0.047	0.0037	24
1 *CHO* vs. 2 *CHO*+*Q*	0.047	0.0029 –0.188	0.047	12
1 *CHO* vs. 4 *CHO*+*Q*	0.029	0.0078 –0.094	0.031	23
1 *CHO* vs. 8 *CHO*+*Q*	0.026	0.012 –0.094	0.033	24
1 *CHO* vs. 16 *CHO*+*Q*	0.062	0.023 –0.13	0.059	22
1 *CHO* vs. 32 *CHO*+*Q*	0.081	0.031 –0.25	0.08	23
4 *CHO* vs. 4 *CHO*+*Q*	0.00009	0.00009–0.0059	0.00098	12
4 *CHO* vs. 8 *CHO*+*Q*	0.007	0.0015 –0.063	0.0078	24
4 *CHO* vs. 16 *CHO*+*Q*	0.015	0.0029 –0.047	0.0140	24
4 *CHO* vs. 32 *CHO*+*Q*	0.018	0.0015 –0.094	0.018	24

were reached. In the test with 1 *CHO* vs. 1 *CHO* + *Q*, the isohedonic concentration was below Q_6 and, unfortunately, could not be determined from the data at hand.

The isohedonic concentrations for the group are shown in Table V. The values shown are for two sets of tests—with 1 *CHO* as a standard, and with 4 *CHO* as a standard.

Table V also gives, for individual rats, the range and mean isohedonic concentrations, based upon tongue-contacts. For an individual rat, the isohedonic concentration is defined as that concentration of *Q* in the compound solution which yields the same number of tongue-contacts as a standard *CHO* solution of lower concentration. The isohedonic concentrations usually fell between two *Q*-values and were then arbitrarily placed at the midpoint.

In some tests with 1 *CHO* as a standard, it was impossible to determine isohedonic concentrations for all rats because the presence of *Q* inhibited the drinking of both fluids to such an extent that insignificant numbers of licks were obtained. For this reason, we have shown at the right of Table V the numbers of rats upon which the individual values are based.

Individual isohedonic concentrations have been plotted in Fig. 1. There are two sets of values—with 1 *CHO* as a standard and with 4 *CHO* as a standard.

Guilford proposed that the term *isohedon* be employed to designate a contour-line of equal affective value on a stimulus-surface, such as a triangular surface with white, black, and yellow at the corners.[6] The term was coined by analogy to contour-lines for equal barometric pressure (isobars) on weather maps, and the like. The two curves shown in Fig. 1 are isohedons in a stimulus-area defined by the concentration of sucrose and the concentration of quinine hydrochloride. Presumably, all compound solutions represented by an isohedon are hedonically equal to each other and to the *CHO*-standard.

Although some of the points on the 1-*CHO* isohedon do not fit the curve very well, there can be no doubt about the objective existence of isohedonic concentrations. At all levels of *CHO*-concentration, points on the 1-*CHO* isohedon are higher on the *Q*-scale than corresponding points on the 4-*CHO* isohedon. This obviously means that more *Q* must be added to a compound solution to bring the hedonic intensity down to the level of 1 *CHO* than the level of 4 *CHO;* or, to state the matter differently, for a given concentration of *Q* more *CHO* must be present in the compound solution to raise the hedonic intensity to the level of 4 *CHO* than to the level of 1 *CHO*.

Discussion

Negative hedonic value of quinine. In the above studies with quinine hydrochloride and distilled water, we found no evidence that quinine, at any concentration, is preferred to water. The hedonic value of quinine is consistently negative. In this respect quinine hydrochloride differs from NaCl, saccharin, and other substances which are hedonically positive at low concentrations and become negative at higher concentrations. Our result agrees with the findings of Benjamin.[7] It fails to support the hypothesis of Schneirla that all sensory excitations lead to approach-reactions at low intensities and to withdrawal at high intensities.[8]

[6] J. P. Guilford, A study in psychodynamics, *Psychometrika,* 4, 1939, 1-23; System in the relationships of affective value to frequency and intensity of auditory stimuli, this JOURNAL, 67, 1954, 691-695.

[7] R. M. Benjamin, Cortical taste mechanisms studied by two different test procedures, *J. comp. physiol. Psychol.,* 48, 1955, 119-122.

[8] T. C. Schneirla, An evolutionary and developmental theory of biphasic processes underlying approach and withdrawal, in the *Nebraska Symposium on Motivation,* 1959, 1-42.

In another study, Kappauf, Burright, and DeMarco found that the palatability level of a sucrose solution (of relatively high concentration) can be raised by addition of a small quantity of quinine.[9] This enhancement-effect must be attributed to some form of interaction between quinine and sucrose, since quinine by itself has no positive hedonic value. In any event, compound solutions that contain both sucrose and quinine may be either positive or negative depending on relative concentrations. The use of compound solutions makes it possible to study the interaction of positive and negative components.

Relativity of aversion-thresholds. Benjamin determined aversion-thresholds for quinine hydrochloride with two procedures: (1) A 24-hr. intake-test with tap water in one bottle and a solution of *Q* in the other. (2) A 1-hr. drinking-test with a single bottle of *Q*-solution presented immediately after a fluid-deprivation of 16 hr.[10] With both procedures, Benjamin presented *descending* series of concentrations whereas in the present work only *ascending* series were used. His aversion-thresholds, expressed here in gm./100 ml. solution, were in the range from 0.0001 to 0.007. The mean for the 24-hr. test was 0.0012, and, for the 1-bottle drinking test, 0.0016. To facilitate comparison with our results, Benjamin's values are plotted in Fig. 1. His range of aversion-thresholds overlaps ours, but in general his values are lower.

Koh and Teitelbaum determined 'absolute' behavioral taste-thresholds in the rat.[11] They employed a high degree of extrinsic motivation. Four rats were trained to discriminate between quinine solutions and distilled water to avoid a shock, and four hungry rats were trained to discriminate between taste-solutions to obtain food. The combined range of quinine-thresholds for these eight rats, expressed in gm./100 ml. solution, was from 0.0003-0.0006, and the combined mean was 0.0005. These values, as shown in Fig. 1, are definitely lower than those obtained in the present study and by Benjamin.

There can be no doubt that aversion-thresholds vary widely from experiment to experiment and with experimental conditions. Various factors might explain the above differences: whether the quinine is presented in solution with distilled water or tap water or in a sucrose-solution; whether there is extrinsic motivation (like that provided by hunger or shock), or whether the animals are need-free and nondeprived; whether the animals are tested continuously for 24 hr. or given a test for 1 hr. or less; whether

[9] W. E. Kappauf, R. G. Burright, and W. DeMarco, Sucrose-quinine mixtures which are isohedonic for the rat, *J. comp. physiol. Psychol.,* 56, 1963, 138-143.

[10] Benjamin, *op. cit.,* 119-122.

[11] S. D. Koh and P. Teitelbaum, Absolute behaviorial taste thresholds in the rat, *J. comp. physiol. Psychol.,* 54, 1961, 223-229.

ascending or descending series are used; and so forth. With diverse procedures, it is not surprising that diverse results are obtained.

In a previous review of studies upon preferential taste-thresholds for sodium chloride, the senior author pointed out that preferential thresholds are a function of *motivating* conditions rather than an index of receptor-sensitivity.[12] A similar conclusion is justified here. The aversion-thresholds to quinine hydrochloride are clearly relative to experimental conditions.

Preferential trends. In the preliminary tests with simple sucrose solutions, we found that the preference for a higher *CHO*-concentration was immediately apparent when the *difference* in concentrations was large, but that the rats had to learn to make a preferential discrimination when the difference was small. This results recalls an experiment by Young and Asdourian in which a 1% NaCl solution was used as a standard in preference-tests with comparison-solutions of 2, 6, 18, 54% sucrose.[13] The group as a whole, as well as individual rats, showed marked preferential trends with repeated tests. When the *CHO*-concentrations were low, the trends were gradual; when the *CHO*-concentrations were high, the trends were steeper. It was concluded that the rate of growth of a preferential discrimination is a function of the *difference* in palatability between the test-fluids, and that this rate of growth depends upon two factors: (1) the relative intensities of hedonic processes evoked by the test-fluids; and (2) the number of repetitions of a choice. In the present study, as well as in that by Young and Asdourian, the implications for the theory of reinforcement are clear. *Hedonic* differences are the main factors in reinforcement.

Isohedonic concentrations. Perhaps the most important result of the present study is the demonstration that isohedons can be plotted with need-free rats in the sucrose-quinine stimulus area. By varying the concentrations of the two components, one can obtain groups of stimuli that are hedonically equivalent, but that differ in sensory quality. This is one of the main values in the use of compound taste-solutions. Earlier work with standard foods (solids and liquids) revealed transitive series, preferential trends, mutations of preference, and the like, but current work with compound solutions reveals isohedonic contours. This is a big step forward in the quantitative and objective study of affective processes.

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[12] Young, The role of hedonic processes in motivation, in *Nebraska Symposium on Motivation,* 1955, 193-238.

[13] P. T. Young and D. Asdourian, Relative acceptability of sodium chloride and sucrose solutions, *J. comp. physiol. Psychol.,* 50, 1957, 499-503.

CONCLUSIONS

(1) In a series of preferencial tests with distilled water and solutions of quinine hydrochloride, no concentration of quinine was found to be consistently preferred to distilled water by need-free (nondeprived) rats. As far as any preference developed, it was a preference for distilled water based upon an aversion to quinine rather than upon any positive incentive value. The higher concentrations of quinine tended to inhibit the intake of both test-fluids.

(2) Aversion-thresholds were determined by adding quinine hydrochloride, step by step, to one member of a pair of sucrose-solutions. The mean thresholds varied with level of sucrose concentration in the range from 0.001 to 0.006 gm./100 ml. solution. The thresholds of aversion to quinine are a function of experimental conditions and not an index of receptor-sensitivity.

(3) In a series of preference tests with simple sucrose solutions, preferential trends were obvious when the difference between sucrose-concentrations was small. The preference for the higher concentration appeared immediately when the difference between concentrations was large.

(4) A preference for the sucrose-solution with higher concentration can be reversed by adding quinine, step by step, to the preferred fluid. The data make it possible to determine what concentration of quinine must be added to make a preferred solution isohedonic to a standard solution of lower concentration. With sucrose standards of 1 and 4 gm./100 ml. solution, we obtained data for plotting isohedonic contours in a stimulus-area defined by the concentrations of sucrose and quinine.