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THE RELATIVE EFFECTIVENESS OF REINFORCERS

City University of New York PH.D. 1982

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THE RELATIVE EFFECTIVENESS OF REINFORCERS

by

Gene S. Fisch

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1982

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This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy

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Abstract

THE RELATIVE EFFECTIVENESS OF REINFORCERS

by

Gene S. Fisch

Advisor: Professor Thom Verhave

This study investigated the effect of amount of reinforcement on behavior.

Seven male hooded rats were exposed to a reaction time procedure in which the concentration of sucrose and salt were systematically manipulated. Six sucrose concentrations and nine salt concentrations were presented in various combinations for each session over three or five consecutive sessions.

The method used a single response lever and two stimuli drawn from two separate modalities. The lever press was distinguished from the lever release.

The organization of the procedure was trial-by-trial. A cycle began with a variable intertrial interval (ITI). After the ITI

elapsed, a light came on. The subject pressed and held the lever for a variable foreperiod until white noise was presented. When the lever was released, the reinforcer was delivered, light and noise terminated, and the cycle began again.

The data consisted of latency of lever release (RT, measured in msec) and rate of responding during the ITI and foreperiod. Median response measures and SIQRs were determined for each subject for the totality of sessions in which a sucrose-salt solution was in effect. Group mean response measures were also determined for each solution.

The results showed that RT was a non-monotonic function of sucrose but an increasing function of salt. Rate was non-monotonic for both sucrose and salt. Group data were initialized at 0% salt for each sucrose parameter and a regression equation obtained for each response measure. These results indicated a strong positive correlation between salt concentration and RT, and a negative correlation between salt and rate. A strong inverse relation between RT and rate was also noted.

The effects of sucrose on RT and rate and the effect of salt on RT are compatible with earlier studies. The strong inverse correlation between RT and rate is at variance with weak inverse correlations found previously. The data were also discussed in terms of an economic model of preference, where RT and rate were parameters for indifference functions. It was noted that neither set of functions conformed to the assumptions for the model.

To my father and mother

Acknowledgement

I wish to acknowledge Drs. Thom Verhave, Brett K. Cole, and Robert N. Lanson for their advice, assistance and forebearance in this endeavor.

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The effect of amount of reinforcement on behavior

It has been shown that the physical properties of the reinforcer are important factors affecting the behavior of the organism. One physical dimension of the reinforcer is its magnitude or "amount." Although researchers have disagreed on the definition of amount (Deese and Hulse, 1967; Kling and Schrier, 1971), it is generally described (Kling and Schrier, 1971) by one of three methods: (1) the mass or volume of the reinforcer; (2) the consummatory behavior; or (3) the concentration (or intensity) of the reinforcer.

Mass or volume

The work of Crespi (1942) and Zeaman (1949) is prototypical of early studies designed to explore the effects of variation in mass or volume of the reinforcer.

Using a group design experiment, Zeaman (1949) placed rats in a start box at one end of a three-foot runway. When the door to the start box was removed, access to the runway was provided. At the opposite end of the runway was a goal box containing different measured amounts of cheese. Two photocells were placed in the alley: one just outside the start box door; the other just outside the goal box door. Two temporal measures, time to leave the start box to the first photocell and time from the first photocell to the second, were recorded. Both measures showed that the latency was inversely related to the amount of cheese.

Consummatory behavior

Variations in amount of food-getting (or consummatory) responding have also been used to study behavior. Namely, it was suspected that consummatory behavior, as opposed to the specific stimulus properties of the reinforcer, determined the effect on behavior.

Wolfe and Kaplon (1941) varied amount of consummatory responding in three different experimental situations: a straight runway; a "detour" runway; and a black-white discrimination. For each situation, each of three groups of chicks was presented one of three reinforcers: one group received a single, whole piece of popcorn; a second group received a single piece of popcorn cut into quarters; the third group received one quarter of a single, whole piece of popcorn. These investigators found that the group which received the four quarters of popcorn showed a higher running speed and eliminated a greater number of errors than either of the other two groups.

Kling and Schrier (1971), however, question the interpretation of these findings. The data show great variability in the dependent measures. Moreover, since the same three groups of chicks were exposed to each of the experimental situations, it is doubtful that the results obtained could be attributed to the food-getting behavior as opposed to the physical amount of the food.

There have been studies which subsequently confirmed the results obtained by Crespi and Zeaman (e.g. Hutt, 1954); however, other researchers have failed to confirm these findings. In particular, Snyder and Hulse (1961) investigated the effects of volume of reinforcement and amount of consummatory responding on behavior. Water-deprived rats were placed in the start box of a straight runway. A drinking tube containing water was placed in the goal box. The volume of water presented to each of three groups of rats was one of several values. Each group was further subdivided according to the number of licks to be made in order to obtain the designated allotment of water. A special pump was used to adjust the size of the drop of water delivered. After training, the results showed that all the rats in the experiment ran down the alley at about the same speed.

Concentration or intensity

Guttman (1953) demonstrated that food concentrations presented in a liquid solvent, e.g. sucrose solutions, could be used as reinforcers; and the delivery of amount could then be held under tighter experimental control.

Thus, amount of reinforcement could be investigated by varying the concentration of the solution.

Using a Skinner box, Guttman investigated the effects of various concentrations of sucrose dissolved in tap water on the rate of bar pressing in rats. Sucrose solutions were delivered by a dipper cup driven by a motor. The volume of the cup was approximately .005 ml. The rats were assigned to one of four groups. Each group was presented one of four concentrations of sucrose (4%, 8%, 16%, and 32% by weight). Guttman looked at response rate under two schedules of reinforcement: crf and fixed interval (FI) 1'.

Analysis of the data showed that, under crf, rate of responding was a non-monotonic function of the log concentration of sucrose; whereas, under FI, rate was a monotone increasing function of sucrose concentration. The relation between concentration and rate varied according to the schedule of reinforcement. In addition, rate was higher in crf than in FI.

From Guttman's demonstration, it might be tempting to conclude that all the variables of reinforcement are stimulus variables; on the contrary, responding may also be a function of other factors. For instance, one important factor which affects responding is the state of the organism at the time of reinforcement. Thus, food can be an effective reinforcer for an organism which has been deprived of it for many hours, but lacks effectiveness for one which has recently eaten. There are variables, then, other than the parameters of the reinforcing stimulus which modify behavior by varying the effectiveness or "strength" of the reinforcer.

Measures of reinforcement strength

In any case, one reinforcer is considered more effective or stronger than another when its influence on behavior is greater. There are several possible measures by which to gauge the strength of rein- forcement; however, these measures do not always correlate well with one another (Hilgard & Marquis, 1940). Using dogs as subjects, Kellogg & Walker (1938) found a weak inverse correlation (-.18) between latency and frequency of leg flexion.

Given the definition of a reinforcer, the rate of responding should be considered an obvious measure of strength. That is, if a reinforcer increases the occurrence of behavior antecedent to its delivery, then a powerful reinforcer will maintain a high rate of occurrence; whereas, a weak reinforcer will maintain a lower rate.

It was previously noted that Guttman (1953), using the rate of bar pressing as a measure, found that response rate increased as the amount of the reinforcer was increased. Other researchers (Verhave, 1956; Stebbins, et al, 1959), have obtained comparable findings using different schedules of reinforcement. On the other hand, there are studies which indicate that rate is invariant when reinforcement amount is varied. Using pigeons as subjects on a VI schedule, neither Jenkins & Clayton (1949) nor Catania (1963a) found significant changes in the rate of keypecking when the amount of grain (as measured by the duration of which the food hopper was presented) was varied. In some sense, however, their findings are more readily comparable to those obtained by Snyder & Hulse (1961), and the problem associated with the definition of amount.

Another method by which to measure the strength of reinforcement presents a behavioral criterion, or set of criteria, which must be met by the organism before the reinforcer is presented. What the animal does, i.e. the "cost" it is willing to "pay", measured along some dimension of behavior, becomes an index of the strength of the reinforcer.

Such a procedure was employed by Hodos (1961) and Hodos and Kalman (1963). Using rats as subjects, Hodos (1961) noted that, for a given reinforcer at certain values of a fixed ratio (FR) schedule, the animal ceases to press the lever. He suggested that a progressive ratio design would be useful in evaluating the relative strength of the reinforcer without reference to the response rate metric. Hodos applied a progressive ratio schedule which compelled the rat to make an increasing number of responses to receive the next reinforcer. For example, a subject would begin a session on an FR 5 with a scheduled increment of 5 responses. In order for the subject to receive its second reinforcer, it would be required to make 10 lever presses; for the third reinforcer, 15 lever presses, and so on until the subject failed to respond for a period of 15 minutes (the "breaking point"), at which time the session was terminated. The maximum ratio sustained before the terminating pause occurred was taken as the index of reinforcer strength. Hodos (1961) found a linear relation between the highest ratio completed and concentration of condensed milk. He also found a linear relation between the highest ratio completed and and the volume of the dipper cup. Other dependent measures - overall rate, running rate and total responses per session - were also examined, but failed to correlate systematically with changes in the size of the progressive ratio. The index was further limited in its usefulness in that only one breaking point measure could be obtained for any given session.

Running speed, or the reciprocal of the time taken by the subject to reach a goal box from a start box, is, in some sense, the runway analogue to free-operant responding under FR. Specifically, the more rapidly the organism moves, the sooner the reinforcer is available. As noted elsewhere, running speed was used by Crespi (1942) and Zeaman (1949) and found to be sensitive to changes in amount of reinforcement. An associated measure of running speed is latency, i.e. the time it takes a subject to leave a start box and enter a runway. Latency has been shown to vary inversely with the amount of reinforcement (Zeaman, 1949; Logan, 1960).

Kling and Schrier (1971) note that there are persistent problems associated with the experimental environment for studies in which runways are used. However well extraneous visual or auditory stimuli are controlled, other factors, e.g. handling of subjects, other uncontrollable stimuli from trial to trial, along with the relatively few trials recorded per subject, generally result in large variances in latency. Such variability may conceal the true relation between latency and amount of reinforcement. The usual remedy for these problems has been the use of data averaged from a large number of subjects; however, Sidman (1952; 1960) has indicated that a group function is not necessarily representative of functions for individual subjects. The solution offered by Sidman was to use the subject as its own control in a free-operant setting. As previously described, however, problems associated with the rate measure and the extent to which it is influenced by the schedule of reinforcement.

Preference as a measure of reinforcer strength

All procedures heretofore described involve the sequential presentation of single reinforcers, using either a trial-by-trial paradigm, or a single manipulandum in conjunction with some schedule of reinforcement. An alternate method of assessing the strength of reinforcement is to present two (or more) reinforcers concurrently. If one reinforcer is chosen rather than, sooner than, or more frequently than another, the subject is said to show a preference. The preferred reinforcer is then thought of as "stronger". This method of reinforcer presentation was employed successfully by Young (1936). Using food-deprived rats as subjects, Young presented various foods (fresh milk, sugar, ground wheat, milk powder, white flour, and but- ter fat) and was able to establish a rank order of preference for these substances. Although a stable, transitive rank order was established, Young could not determine by how much, say, milk was preferred to sugar since the preferred alternative was usually chosen on a high proportion of trials.

A similar choice procedure adapted for the free operant response was employed by Catania (1963a). Food-deprived pigeons were permitted to peck at either one of two keys. Both keys were made available concurrently, and responses made to either were independently reinforced (concurrent VI 2' VI 2'). A two-second changeover delay (COD) was also used to prevent a response on one key from coming under the control of reinforcement by the other.

After the pigeon's behavior stabilized, Catania varied the amount of reinforcement by varying the duration of the hopper presentation (3.0, 4.5, or 6.0 seconds). Catania found that, with the concurrent procedure, response rate was linearly related to reinforcement duration (he also noted that this relationship was similar to the one obtained by Herrnstein (1961), who found a linear relationship between response rate and reinforcement rate.).

Catania also investigated the effect of reinforcement duration on response rate under a simple VI 2' schedule, using only one of the pair of keys. He confirmed the results obtained by Jenkins and Clayton (1949), and concluded that the rate measure in a choice procedure was more sensitive to the parameters of reinforcement than was the rate measure used with a single manipulandum. Moreover, concurrent procedures permitted comparative measurements to be made relative to some reinforcer which served as a standard.

In a subsequent review of concurrent operant procedures, however, Catania (1966) appeared less enthusiastic about the sensitivity of rate to the parameters of reinforcement. Specifically, he noted that the incidental pairing of some behavior patterns with the delivery of reinforcement after the COD terminated generated differences in concurrent performances maintained by similar schedules of reinforcement. "These differences complicate the comparison and analysis of the performances" <Catania, 1966, especially pp.218-219>.

Although preference is usually demonstrated by choice or comparative procedures, Pfaffman (1969) has indicated that preference may be otherwise defined. In particular, he stated that a preference could be made manifest in the single bottle paradigm if an organism accepts one particular reinforcer in greater quantities than another; or, as in the free operant procedure using a single reinforcing stimulus, if some parameter of the response would reveal preference.

One such method was applied by Stebbins (1962). He developed a technique for measuring reaction time in lower animals (Stebbins & Lanson, 1961). Food-deprived rats were trained to press and hold a telegraph key in the presence of a visual stimulus. They continued to press the key until a second cue (an auditory stimulus) was presented. Subsequent release of the key during the presence of the auditory stimulus was followed by the delivery of 0.15 ml of one of several concentrations of sucrose in solution with tap water (20%, 5%, or 0%). The rats' latency to key release to the second (auditory) stimulus, its reaction time, was the primary dependent measure. Stebbins noted that the median latency and the variability of the latency measure increased as a result of the shift from higher to lower concentrations.

Reaction time as a measure of preference If, as Pfaffman suggests, preference for some quantifiable aspect of the reinforcer, e.g. amount, is defined in terms of some quantifiable aspect of the response, Stebbins' RT procedure possesses several distinct virtues.

Unlike rate, RT has not been found to be a equivocal response measure when used in studies which vary amount of reinforcement. Stebbins' procedure also permits aggregation of a great many data points per session, as opposed to methods which employ progressive or adjusting ratio procedures e.g. Hodos & Kalman, 1963; Verhave, 1963. As a measure of latency, Stebbins' procedure is superior to the runway in that variability from uncontrolled (or uncontrollable) factors is minimized. As the measure of a continuous variable, RT offers a ratio scale metric whereas Young's procedure yields only rank order. Amount of reinforcement can be measured by varying the concentration of solutes in some solution. For example, if the parameters of salt concentration are varied with parameters of sucrose, the relative effect of salt can be measured by the change in RT. Similarly, the relative effect of sucrose at a given parameter of salt can also be determined.

Interrelation of response measures

Hilgard (1937) has stated that in order to demonstrate the effectiveness of a reinforcer on conditioning, it is necessary to quantify measures of effectiveness. At the empirical level, the strength of conditioning is determined from the strength of the response. Several measures of responding are available: magnitude, latency, number, and frequency, among others. The question as to which response measure best indicates the strength of conditioning is again empirical . Any reliable measure is appropriate for a given experiment. Thus, if more than one measure can be determined, an analysis of the correlations between them may indicate which are most useful.

With the separation of conditioning into two types (Skinner, 1938; Hilgard & Marquis, 1940), response measures were allocated to one or the other case. To justify this state of affairs, Keller and Schoenfeld (1950) argued that: "neither <latency or magnitude> is satisfactory in determining the strength of an operant. Latency can have no meaning in the absence of an identifiable stimulus from which to measure the s-r interval; and the magnitude of an operant response does not change during conditioning in the orderly manner that typifies the respondent." (p.50)

Latency and magnitude were thus relegated to respondent procedures; whereas frequency was consigned to the operant. "Our best measure of operant strength is frequency of occurrence. An operant is strong when emitted often within a given period of time; it is weak when emitted rarely....in the case of the respondent, frequency is a useless measure in fact, no measure at all..." (ibid.).

Much has been made for the use of the rate measure in the free-operant procedure, and for the free-operant procedure in general. Skinner (1966) stated that because response rate operates in real time it is therefore more meaningful than discrete trial-by-trial procedures.

On the other hand, it has been argued that the organism's own behavior may interfere with its rate of responding (cf. Catania, 1966; Platt & Spence, 1967). Marx (1969) noted that the discrete trial procedure has the advantage of controlling this kind of behavior by restricting its occurrence to a specific temporal interval. Such a method might thus provide the basis for a reconciliation between the response measures of latency, magnitude and rate.

The implementation, then, of some

"controlled-operant" procedure could amalgamate the advantages of discrete trial methodology with those of the free operant. The technique for measuring RT devised by Skinner (1946) and developed by Stebbins and Lanson (1961) marks a step towards the convergence of these two methodologies. In this procedure, the organism is free to respond at any time, and a rate measure can therefore be determined. Moreover, the procedure is essentially composed of discrete trials in which the latency to bar release of the discriminative operant is the primary measure. If there is a high correlation between these response measures, then both are reliable as metrics by which to determine the strength of conditioning.

As indicated elsewhere, early studies e.g. Kellogg and Walker (1938), note weak inverse correlations between latency and frequency. Hull (1943), on the other hand, indicates that there is an inverse relationship between the magnitude of responding and latency for increasing amounts of reinforcement. Mueller (1950) has also provided a theoretical account of a possible relationship among measures of responding. In particular, he offers a probabilistic model of responding and its relation to rate and latency. McGill (1962), however, has criticized the basic assumption of the model by pointing out that sequences of intervals of responding are not randomly generated.

Based on his findings (Stebbins, et al, 1959; Stebbins, 1962), Stebbins suggested that, at least empirically, latency and response rate were inversely related. Since it is the case that, in the RT procedure, the subject has continuous access to the lever during the session (and a pilot study here noted lever pressing on occasions other than when reinforcement was available) , a response rate measure can also be computed.

A model for preference

Interest in questions associated with preference and choice extend beyond the pale of psychology. Recently, Rachlin (1975; also Rachlin, et al, 1976) devised a procedure to study "economic" choice behavior with non-human subjects. Using non-deprived rats in a two-lever experimental chamber, Rachlin permitted his subjects to choose between flat root beer (RB) or tom collins (TC) mix according to which lever was pressed. By manipulating the volume of the reinforcer ("price"), he found that he could shift these subjects' baseline preferences from one "commodity" to another. One subject shifted its preference to TC from RB after the cup size for RB was halved and the cup size for TC doubled.

In other words, varying the volume per

reinforcer resulted in a change in the number of responses for one reinforcer over another. These results confirmed the findings previously obtained by Collier and Myers (1961), in which the parameters of sucrose concentration and dipper cup size were varied. Using food-deprived rats as subjects, these investigators noted that, at low concentrations of sucrose (4%), a significantly greater number of lever-presses were made for larger cups than for smaller ones. On the other hand, at a much higher concentration (32%), the number of responses made early in the session were much the same for all cup sizes but the rate of responding for the larger cups declined over the session length. Clearly, these findings indicate an interactive effect among the parameters of concentration and volume.

In Rachlin's study, only the parameters of volume were manipulated. The question as to the effect (if the "quantities" of the "commodities", on preference patterns was not addressed. The importance of the effect of concentration to this model of preference will be discussed later.

The model Rachlin employed to explicate his findings comes from economics and is known as the theory of consumer demand. It is concerned with the structure of choices for commodities made by a consumer confronted with various prices of several commodities, along with constraints placed on total expenditures. The "budget set" is defined as the set of all ordered n-tuples of commodities which the consumer can afford to purchase at a given set of prices, without exceeding some income constraint. In a world composed of only two commodities, the budget set can be represented by all (Xi, Yi) ordered pairs which satisfy the condition:

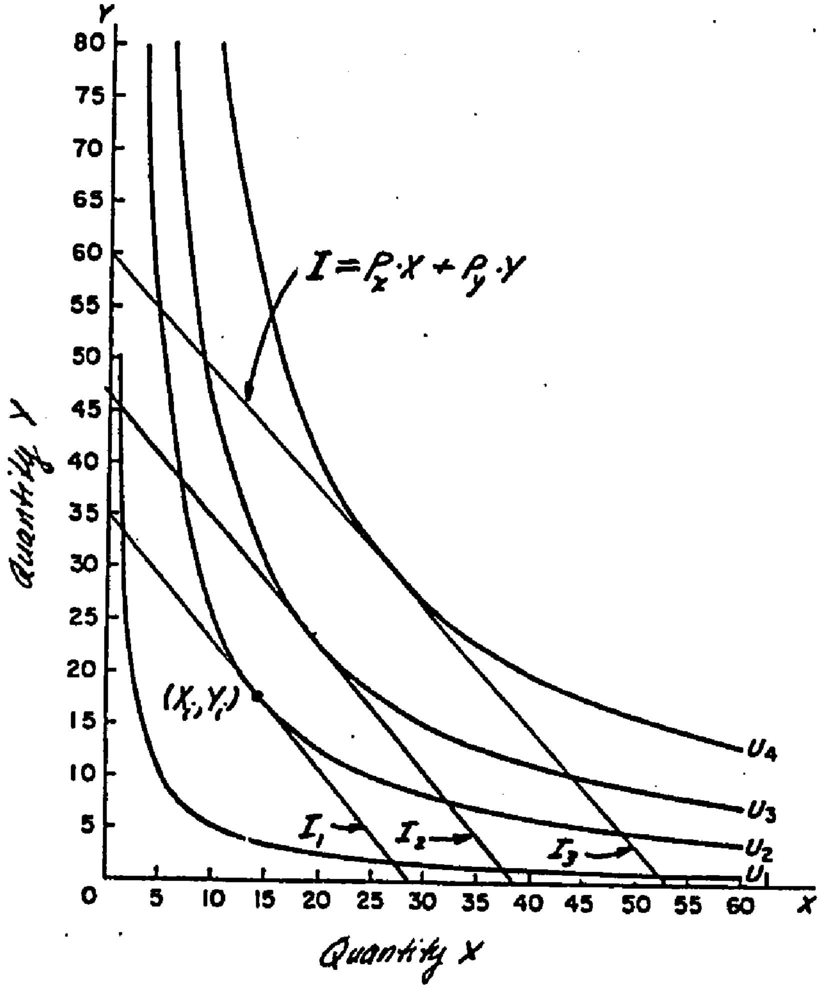
$$(Px)(Xi) + (Py)(Yi) \leq I,$$

Where Px and Py represent the exchange rates or prices of the commodities Xi and Yi (the quantities of X and Y purchased as these prices), and I is the income constraint.

Figure 1 presents a hypothetical example of a two-commodity model. The values along the X and Y axes represent amounts of commodities X and Y, and (Xi, Yi) represents a typical ordered pair of X and Y. I1, I2, and I3 are different income levels (constraints on spending), and $I1 < I2 < I3$. U1 through U4 represent a family of non-intersecting "indifference" functions for pairs of commodities X.and Y, and $U1 < U2 < U3 < U4$. An indifference function is the set of all (X, Y) pairs such that the consumer shows no preference for any one pair over another in the set. However, any ordered pair from the set U2 is preferred to any ordered pair from the set U1. Thus, the "higher" the indifference

Figure 1. _A hypothetical example of a two-commodity model_.

This figure illustrates a two-commodity model use in economic demand theory. The two commodities, X and Y, are represented in number of units for each commodity along the abscissa and ordinate, respectively. Indifference functions U1 to U4, and budget constraints I1 to I3, are also indicated.


Y
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
55
60
X
Quantity Y
Quantity X
$I = P_x \cdot X + P_y \cdot Y$
(X_i, Y_i)
I_1
I_2
I_3
U_4
U_3
U_2
U_1

function, the greater the preference.

The consumer, in attempting to maximize his preferences subject to the income constraint is assumed, given income I1, to prefer pairs of (X, Y) values from U2 as opposed to U1. In theory, he will maximize his consumption (and spend all his income) at (Xi, Yi), where the income constraint, I1, is tangent to U2.

Several assumptions about indifference functions are fundamental to the model: that these functions are totally ordered i.e. one function never intersects another; and that they are monotone decreasing. Moreover, the shape of the family of indifference curves determines the effect that changes in price for the commodities in question will have on their consumption patterns. For example, relatively flat functions will have little effect on consumption patterns for commodity Y when the relative prices for X and Y are changed.

In any case, the underlying preferences for these commodities determines the curvature of the indifference functions. In the absence of these data, only limited inferences can be made, and only with respect to a single function. It behooves the economist to determine the family of functions before attempting to manipulate other parameters of the model, and these functions need to be determined empirically (cf. Wallis & Friedman, 1942).

Athough demand theory was developed by economists, the few attempts to determine empirical indifference functions have been made by psychologists. (Thurstone, 1931; Davis, 1958; Young, 1960; Young & Christensen, 1962; Young & Schulte, 1963; Tversky, 1969). Specifically, Young and his associates investigated the effects of compound taste solutions on preference.

Using non-deprived rats, Young & Christensen (1962) found that one compound of a sucrose-sodium salt solution could be "equally palatable" to a different sucrose-salt solution. Equal palatability was determined by the percentage of licks made by these subjects to each of two different sucrose-salt solutions. Thus, a preference between two solutions was revealed from the difference in that percentage (This procedure and the findings obtained from it will be elaborated in the Discussion section).

Purpose

It has been demonstrated that the amount of the reinforcer can be an important variable affecting behavior. Amount has been defined by several methods, but concentration (or intensity) is the one best controlled in an experimental environment. Amount of reinforcement can also be an important factor in evaluating its effectiveness or strength. The strength of a reinforcer is determined by its influence on behavior . Several measures of responding were examined to find which were the most reliable for determining reinforcer effectiveness. Procedures determining reinforcer effectiveness were also discussed. Concurrent (preference) procedures were compared with sequential procedures. It was indicated that preference could also be defined for a sequential procedure. It was suggested that a (sequential) RT procedure for lower animals could be used to measure preference. This researcher conjectured that if the RT procedure could incorporate more than one response measure, correlations between RT and rate could be found to determine which is more reliable in measuring reinforcement strength. A model for preference was also proposed. The model sought to analyze preference by investigating families of indifference functions. These functions need to be determined empirically before inferences can be drawn about preference; their characteristics are basic to the further elaboration of a theory of consumer demand.

This study, then, serves several purposes. One is to investigate the effect of amount of reinforcement (using various concentrations of sucrose-salt combinations in solution with distilled water) on behavior (as measured by the latency of lever release, and by the rate of responding). The second is to examine the efficacy of reinforcement on these response measures by determining their correlation. The third is to determine empirically a set of indifference functions, using equal response measures, as a means by which to determine the relative preferences of two different commodities (in this instance, of sucrose and salt); and to evaluate the implications of these functions to the economic model.

Method

Subjects: The subjects were seven male rats of the Long Evans strain, approximately 30 to 60 days old at the beginning of the experiment. Throughout the initial training period, Purina lab chow was continuously available in the living cage. The subjects were water-deprived approximately 10 hours. Each subject was run daily until 100 reinforcers were presented. After each session, water was supplied to the living cage until approximately 10 hours before the next session.

Apparatus: The experimental chamber was a BRS/LVE SEC-002 rodent environment cage. The intelligence panel in the chamber held two levers, of which only the one on the right side was used. The lamp (S1) above the lever was also employed during the session. A small, 8-ohm speaker, mounted behind the intelligence panel, delivered white noise (S2) to the chamber from a Grason-Stadler 901B noise generator set at 74-76 dB(A). A solenoid-operated dipper located 2.25" from the lever presented .08 ml of a sucrose-salt solution by weight as reinforcement. A houselight, located outside the chamber but inside the cage, provided illumination for the chamber. Programming and recording were regulated by the appropriate relay and timing devices. Responses and reinforcers were recorded on counters. Reaction times (RT), measured in milliseconds (msec), were recorded by a Coulbourn Instruments printout counter (model # R21-01) which was connected to a Coulbourn 1hz free running crystal oscillator, reliable to 1/2 microsecond (model #S51-01).

Procedure:

Conditioning: All subjects were placed in the experimental chamber and dipper-trained in the presence of the cue light (S1). The subjects were then trained to press the lever in the presence of S1. The lever press (R1) produced noise (S2) and the lever release (R2) terminated S1 and S2, raising the dipper for 3 sec and producing a 4% sucrose solution as reinforcement. Approximately 100 reinforcers were presented daily.

Discrimination training: onset of S1 was made contingent on the absence of a lever press for a variable time interval (ITI) which ranged from 5 to 21 seconds. Each lever press during ITI reset the interval timer and postponed S1. In the presence of S1, a lever press of 0.3 second duration (R1) resulted in the presentation of S2. If R2 occurred during S1 and S2, a reinforcer was delivered, and S1 and S2 were terminated. After the termination of reinforcement, the ITI began. A lever press of less than 0.3 second duration in S1 had no effect on the experimental conditions. Discrimination training continued until responses during ITI were minimal.

Penalty procedure: Following discrimination training, an additional component to the procedure was introduced in an attempt to reduce the number of responses which occurred during the no-light condition. If a response occurred during the no-light interval, the houselight was turned off for 13 seconds. After the houselight came back on, the penalty procedure remained in effect for at least 5 seconds, or until the ITI timed out.

Differentiation of duration: After the penalty procedure was implemented, duration of each lever press (the foreperiod) necessary to produce the noise was increased from 0.3 to 2.0 seconds, in 0.2 second steps. A lever press of less than 2.0 sec duration reset the foreper- iod clock, while S1 remained on. To reduce the possibility that the subject might anticipate the onset of S2, two separate foreperiod clocks were used: one was set at 1.5 sec; the other at 2.0 sec. Two probability generators (BRS/LVE # PB-903), each set at p=.5, were interposed between the lever switch and the two clocks. One probability gate determined which clock would operate when R1 occurred; the other determined whether a given clock would continue to count if another R1 occurred after a premature bar release. A foreperiod of variable duration (0.0 to 2.0 sec) was thus implemented.

Limited hold: Following differential training, another component to the procedure was introduced to reduce the variability in RT. If the rat pressed and held the lever during the presentation of S1 and S2, but failed to release the lever within 2 seconds after the onset of S2, no reinforcement was delivered. The 2 second limited hold was gradually reduced to one second.

Pilot study:

During an initial pilot study, the subjects' regimen was shifted as follows: the rats were gradually reduced to 80% ad libidum weight and food-deprived. In place of lab chow, water was made continuously available in the living cage. The subjects were fed just enough lab chow at the end of each session to maintain their weight at approximately 80% ad lib. Three subjects from the pilot study (C1, C2 and C8) were selected. These rats were given varying concentrations of sucrose (25, 5, 20, and 10%). Percent concentration of sucrose was determined by a ratio of the gram amount of solute (sucrose) to 100 grams of solvent (distilled water). New sucrose concentrations were prepared every other day. These subjects were each run for one session daily over five consecutive days. Cups were cleaned after each session, as was the experimental chamber. The subjects were then returned to 5% sucrose. At this point, varying concentrations of (reagent pure) sodium chloride (salt) were added to the

5% sucrose solution. The subjects were each run for one session daily over three consecutive days at the given sucrose-salt concentration. The salt concentration was then increased, and the subjects run again for three consecutive days. Salt concentration was increased in this manner until the subjects showed a marked change in behavior (see below). At this sucrose-salt concentration, the rats were each run for one session daily over five consecutive days, then returned to baseline (5% sucrose, 0% salt) for five consecutive days.

To give an example: After each animal was brought to the 5% sucrose baseline, 1 gram of salt was added to the 5% sucrose solution. The subjects were run for three consecutive sessions at this sucrose-salt concentration, after which 2 grams of salt was added to a 5% sucrose solution. The subjects were run again for three consecutive sessions at this sucrose-salt concentration. At this point, 2.5 grams of salt was added to a 5% sucrose solution, where a marked change in the the subjects' behavior was recorded i.e. longer RTs and longer session lengths. The subjects were then run for five consecutive sessions at this sucrose-salt concentration, after which they were returned to the 5% sucrose baseline for five consecutive sessions. The subjects were then shifted to a 10% sucrose baseline for five consecutive sessions, whereupon varying concentrations of salt were added to the 10% sucrose solution in the manner just described.

Varying salt concentrations were subsequently added to 20, 25, and 15% sucrose concentrations by this method. Following this procedure, lower concentrations of sucrose were presented (4%, 3%, 2% and for one subject, 1%) until behavior was disrupted in the fashion described earlier.

At about the time these lower sucrose concentrations were effected, a second group of trained rats (C4, C5, C6, and C9) were introduced to the sucrose-salt regimen in the following manner: each subject was presented with a 25% sucrose solution in one session daily over five consecutive days. Varying amounts of salt were added to the 25% sucrose solution. At any given sucrose-salt concentration, the subjects were run for five consecutive sessions. The amount of salt was increased until the subjects showed longer RT's and session lengths as previously mentioned. The subjects were then returned to the baseline sucrose concentration for five consecutive sessions. At this point, a new sucrose concentration was presented for five consecutive sessions. Sucrose baselines were presented in decreasing order from 25% to 5%, in 5% decrements. At each new sucrose concentration, varying amounts of salt were added to the given concentration of sucrose in the manner indicated.

All seven subjects received 100 reinforcers for each daily session.

A table of sucrose-salt concentrations used in this study appears in Table 1. Not all subjects were exposed to all combinations.

Table 1: Table of sucrose-salt concentrations used in this study.

Percent Salt	Percent Sucrose 1	2	5	10	15	20	25
0	Y	Y	Y	Y	Y	Y	Y
1	-	-	Y	Y	Y	Y	Y
2	-	-	Y	Y	Y	Y	Y
2.5	-	-	Y	-	-	-	-
3	-	-	-	Y	Y	Y	Y
4	-	-	-	Y	Y	Y	Y
5	-	-	-	-	Y	Y	Y
5.5	-	-	-	-	-	Y	-
6	-	-	-	-	-	Y	-

Results

The experiment was designed to study the relation between reaction time and sucrose or sucrose-salt concentrations. A response rate measure was also examined as it related to concentrations of sucrose and sucrose-salt. It was computed as follows: the total number of responses during each session were tallied, minus those which occurred during the blackout component and those responses which were reinforced. The accumulated blackout time was then subtracted from the session length. The rate measure was obtained by dividing the remaining time (in minutes) into the number of responses.

Median reaction time and semi-interquartile range (SIQR) were determined for each session. The arithmetic mean of the median RT was computed for each subject for the total number of sessions at each point. In addition, a pooled median RT and SIQR were calculated for each subject across all sessions at each point. The pooled median differed by less than 5 msec from the arithmetic mean of the median. Since the difference between the calculated medians was less than 3%, the pooled median was arbitrarily chosen.

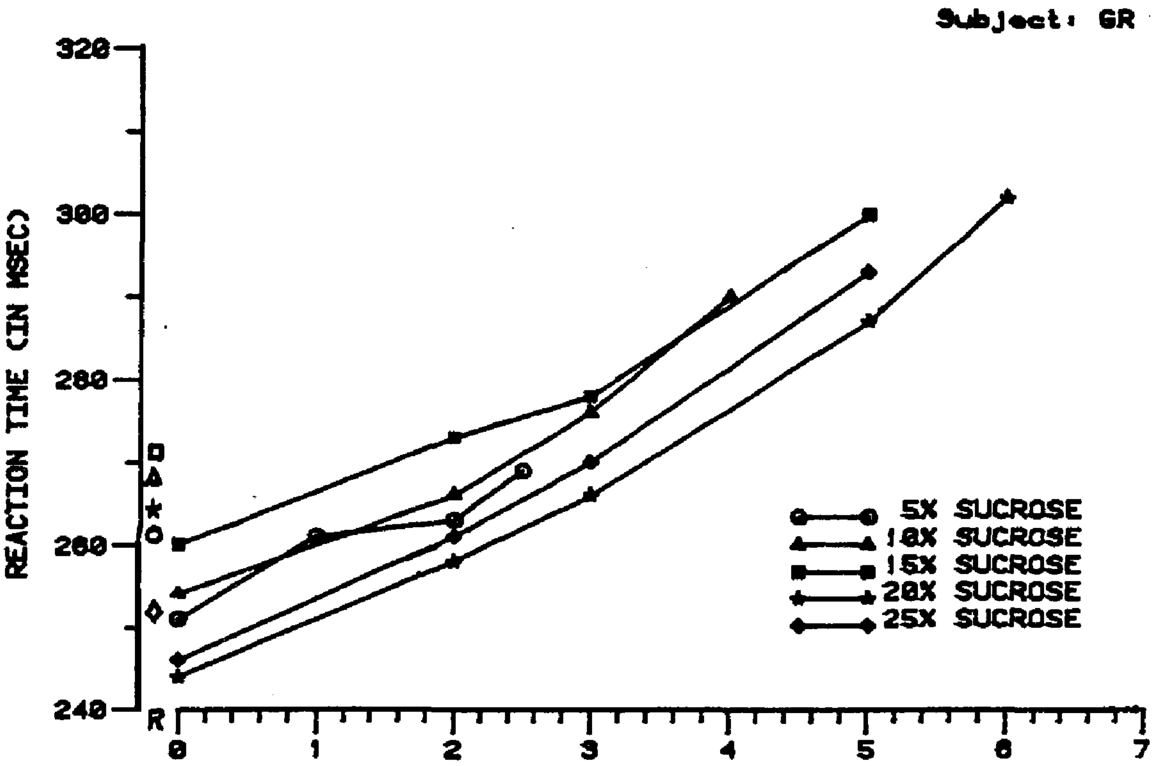
The group mean (GM) of the pooled median RT's for all subjects was computed for each sucrose or sucrose-salt concentration, as well as the GM of the SIQR. Since both the number of responses and session time varied for each subject, the median response rate was used and determined for each subject for the total number of sessions at each point (cf. Wert, 1938). GM of the median response rates for all subjects were computed, as well as the GM of their SIQR's for each sucrose-salt solution (see Figures 2 through 5, inclusive). Baseline recovery of latencies and response rates for each sucrose parameter are indicated by the symbols to the left of the functions.

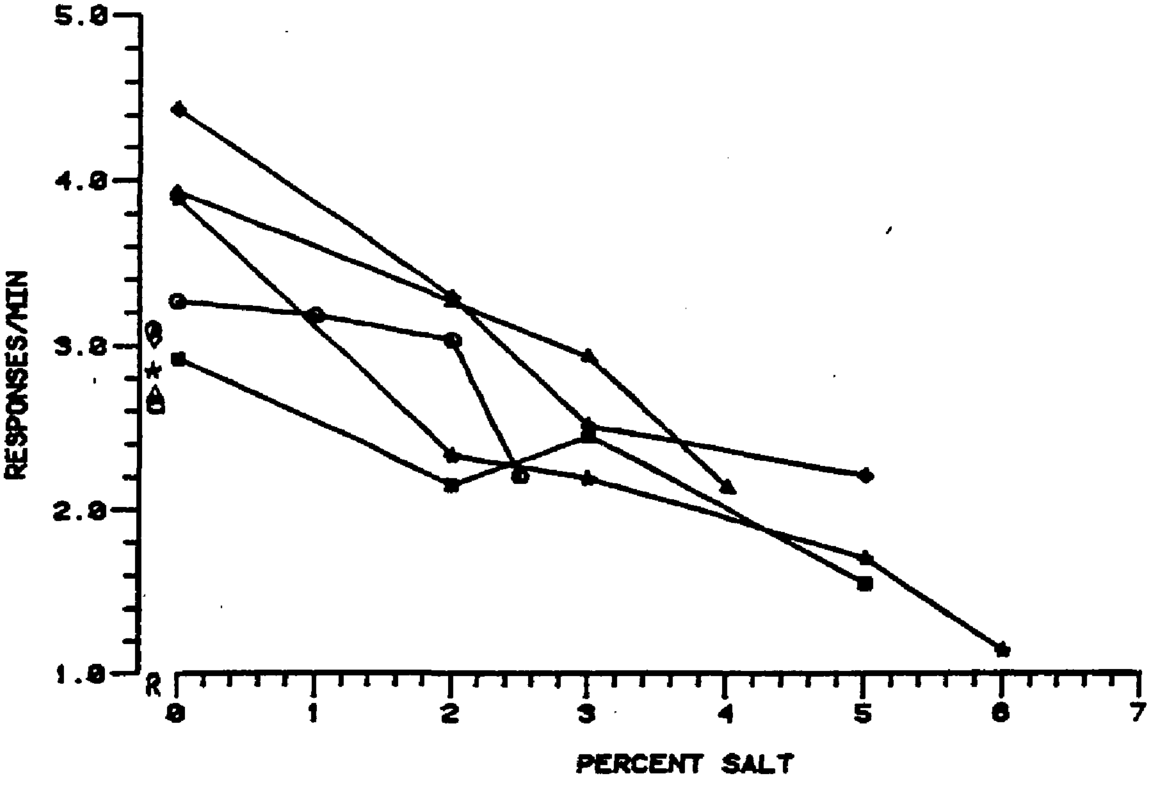
The group mean RT and group mean response rate for 25% sucrose 3% salt, and for 20% sucrose 6% salt were obtained as follows: the median RT for C1, C2, and C8 at 25% sucrose 3% salt were added to the median RT for C4, C5, C6, and C9 at 25% sucrose 4% salt, and then averaged. Similarly, the median RT for C1, C2, and C8 at 20% sucrose 6% salt were added to the median RT for C4, C5, C6, and C9 at 20% sucrose 5.5% salt, and then averaged.

Figure 2 shows a family of functions in which the dependent variables were group mean RT (upper panel) and group mean response rate (lower panel). In this figure, sucrose concentration is the parameter and salt concentration is the independent variable. The functions in this figure indicate that as the amount of salt is increased, reaction time becomes longer. Moreover, as salt is increased, the response rates generally decrease. The family of functions for which

Figures 2. and 3. Group mean RT and response rate.

These figures show families of functions in which the dependent measures are group mean RT (upper panel) and group mean response rate (lower panel). In figure 2, sucrose is the parameter and salt is the independent measure. In figure 3, salt is the parameter and sucrose is the independent measure.


Subject: GR
REACTION TIME (IN MSEC)
320
300
280
260
240
R
0
1
2
3
4
5
6
7
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE


RESPONSES/MIN
5.0
4.0
3.0
2.0
1.0
R
0
1
2
3
4
5
6
7
PERCENT SALT

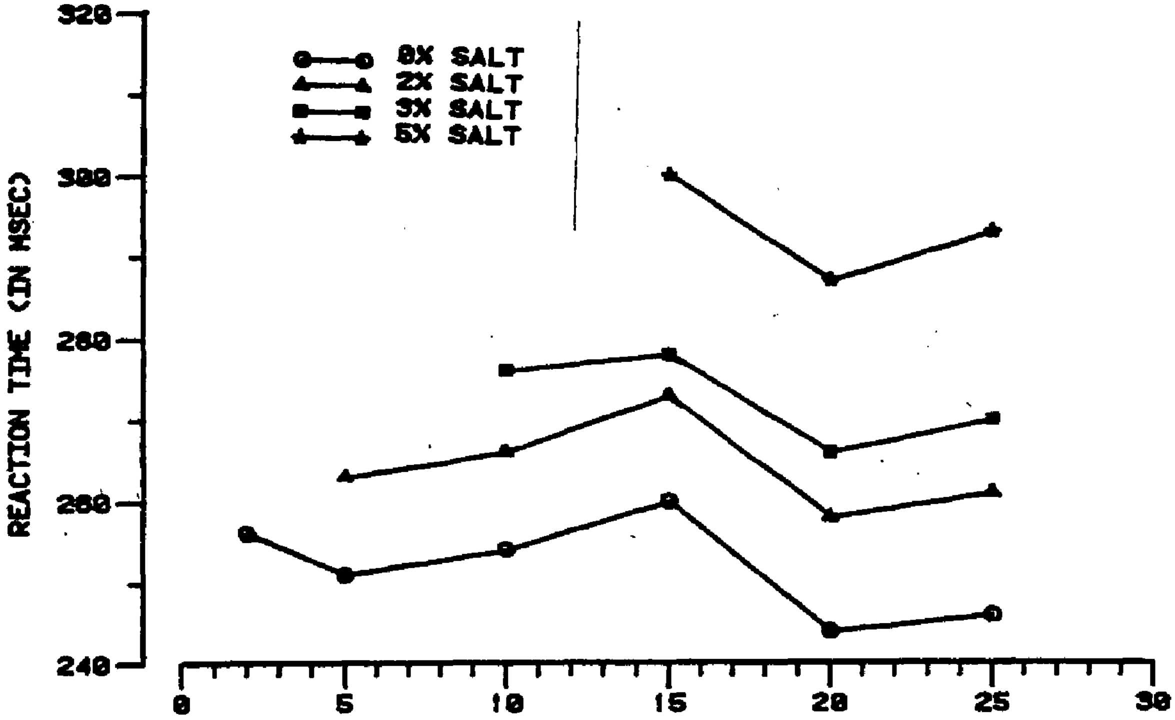
RT is the dependent measure is more orderly than the family of functions for which response rate is the dependent measure.

While RT functions are more systematically ordered than rate functions, the family of RT functions is not totally ordered with respect to the sucrose parameter. Thus, the 20% sucrose function appears below all other functions, over the range of salt values. The functions are roughly parallel to one another and are ordered as follows: 20%, 25%, 5%, 10%, and 15%. Similarly, the response rate functions are not totally ordered with regard to the sucrose parameter. In Figure 3, salt concentration is the parameter and sucrose is the independent variable, the dependent variables are the same as in Figure 2. The functions indicate less than 10% change in RT as sucrose is increased. These functions are totally ordered with respect to the salt parameter. Increasing salt from a lower value to a higher one shifts the function upward with respect to RT.

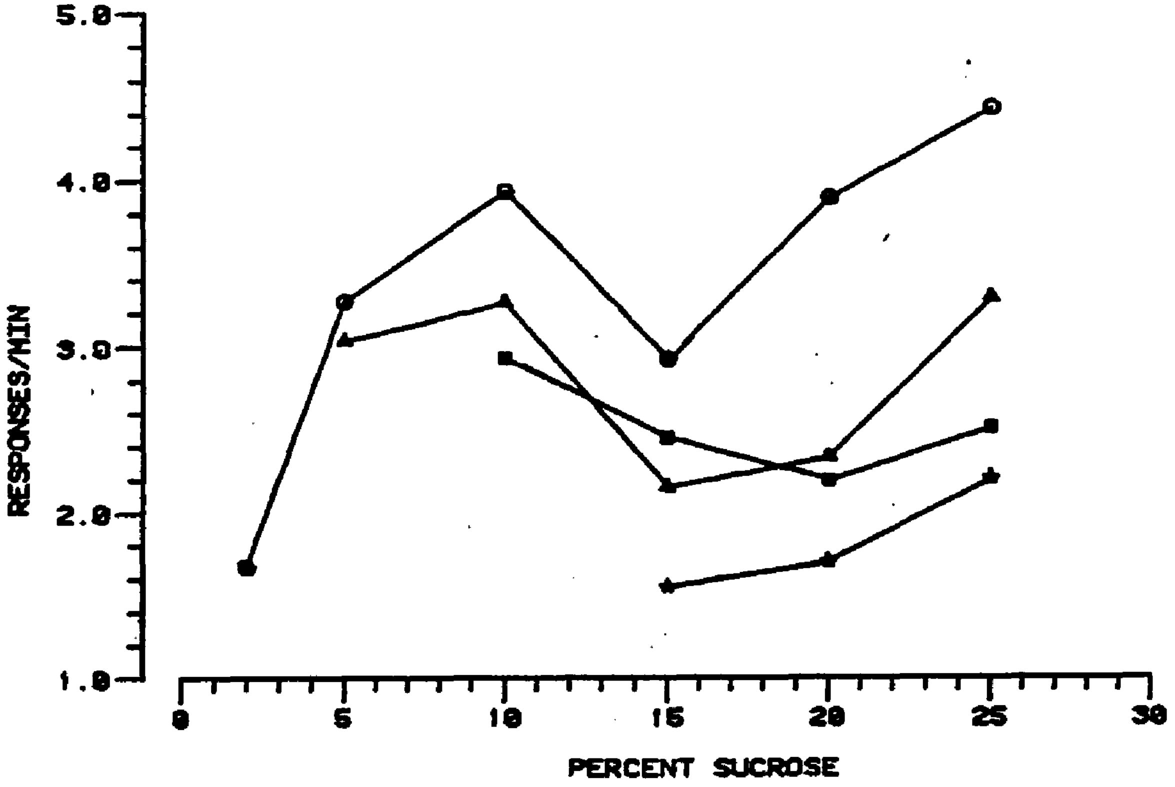
The response rate functions (Figure 3, lower panel) show an orderly relationship similiar to those obtained for RT. These functions are also non-monotonic. One exceptional point at 15% sucrose 3% salt, appears to spoil the orderliness of the relations across functions.

Figures 4 and 5 present the group mean variability associated with each of the response measures. Figure 4

Subject: GR



0% SALT
2% SALT
3% SALT
5% SALT
REACTION TIME (IN MSEC)
320
300
280
260
240
0
5
10
15
20
25
30

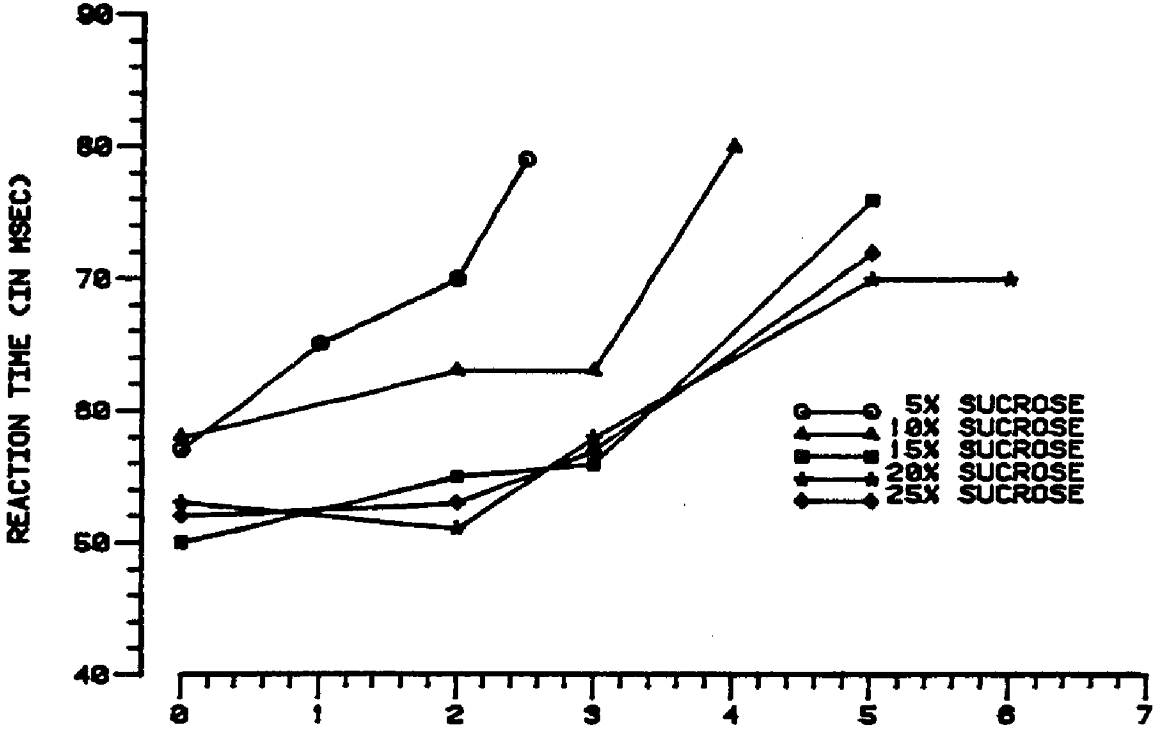


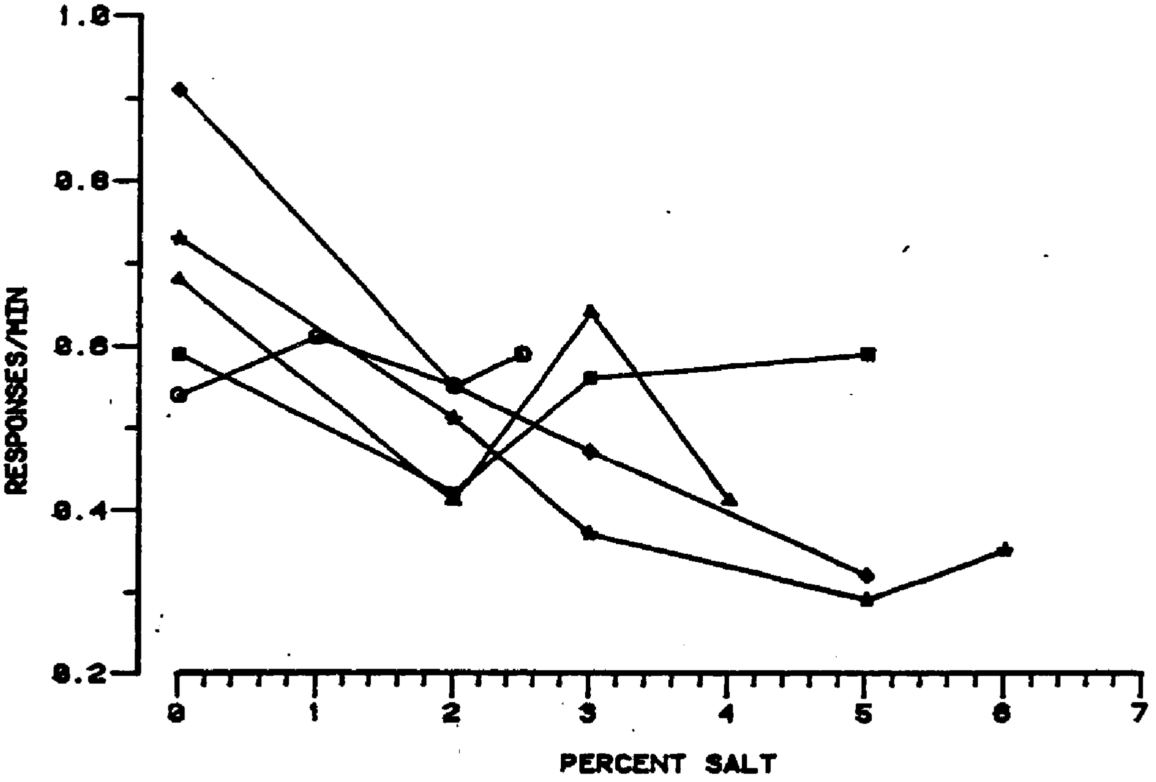
RESPONSES/MIN
5.0
4.0
3.0
2.0
1.0
0
5
10
15
20
25
30
PERCENT SUCROSE

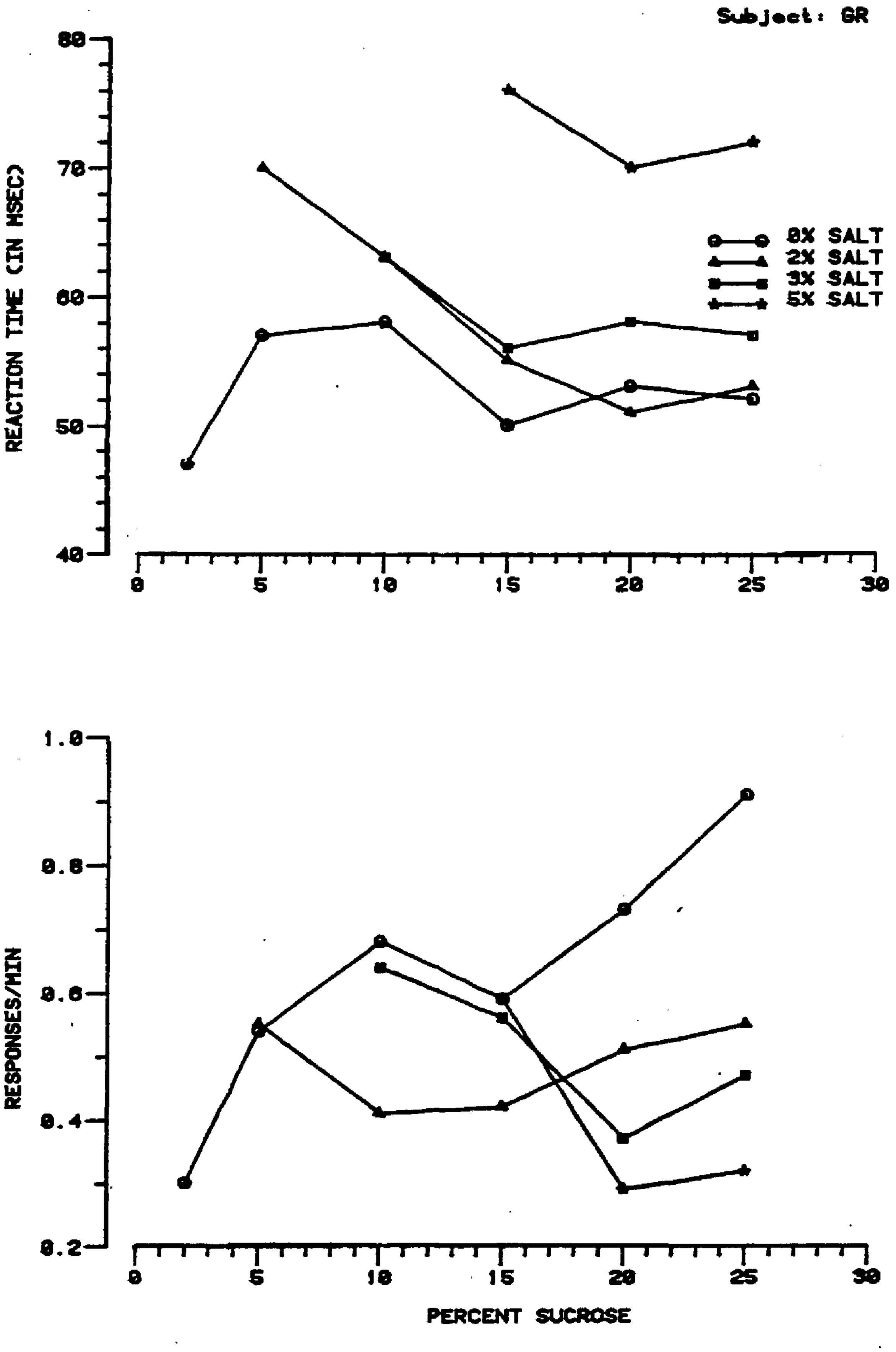
Figures 4. and 5. Group mean SIQR for RT and response rate.

These figures present the group mean variability associated with each of the response measures. Figure 4 shows a family of functions for RT SIQR (upper panel) and response rate SIQR (lower panel), where sucrose is the parameter and salt is the independent measure. Figure 5 shows a family of functions for RT SIQR (upper panel) and response rate (lower panel), where salt is the parameter and sucrose is the independent measure.

Subject: GR


REACTION TIME (IN MSEC)
90
80
70
60
50
40
0
1
2
3
4
5
6
7
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE


RESPONSES/MIN
1.0
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
PERCENT SALT


Subject: GR
REACTION TIME (IN MSEC)
80
70
60
50
40
0% SALT
2% SALT
3% SALT
5% SALT
0
5
10
15
20
25
30
RESPONSES/MIN
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
PERCENT SUCROSE

shows a family of functions for RT semi-interquartile range (upper panel) and response rate semi-interquartile range (lower panel), with salt as the independent variable and sucrose as the parameter. In the upper panel, group mean variability gradually increases as salt is increased. At concentrations of sucrose at or above 15%, the functions overlap each other across the range of salt values; at the lower sucrose values, the effect of the salt occurs at lower concentrations, and variability increases more rapidly.

The lower panel in Figure 4 shows that, in general, as the amount of salt is increased, GM rate variability (SIQR) decreases.

Figure 5 is a plot of the group mean variability as a function of sucrose concentration, with salt as the parameter. The upper panel presents RT variability, measured in milliseconds. This family of functions is relatively flat over the range of sucrose values. At or below the 3% salt parameter, the functions roughly overlap one another; at the 5% salt parameter, the function is shifted upward.

The lower panel presents response rate variability, measured in responses per minute (r/min). Variability is greater at 0% salt than at other salt values. Also at 0% salt: variability increases as sucrose concentration is increased. There appears to be no orderliness at the other salt parameters (Tables for individual subjects' SIQRs can be found in the Appendix in Tables A1 to A10.).

To determine whether SIQR was related to the median response measure, SIQR was plotted against median RT and median rate. Figure 6 is a plot of variability as a function of RT (upper panel) and response rate (lower panel), respectively. The family of functions in the upper panel are trend lines plotted by eye of the GM of the median SIQR's on the GM of the median RT's, with sucrose as the parameter. The slope is flattest for the trend line for the 25% sucrose parameter. The slope gradually increases at lower sucrose concentrations.

The reverse is true when variability of response rate is measured (see Figure 6, lower panel). Trend lines were drawn for group mean semi-interquartile range (in r/min) on group mean response rate. Here, the steepest slope is associated with the largest sucrose parameter. The slope decreases in an orderly fashion as sucrose parameters become smaller.

An attempt was made to compare the findings in this study with those of other investigators in which rate was a function of sucrose concentration (Guttman, 1953; 1954; Stebbins, et al, 1959). Percent concentration by weight in these earlier studies (see Figure 7) was obtained in the manner suggested by Pfaffmann, et al (1954). Specifically, concentration

Figure 6. Group mean SIQR as a function of group mean RT and group mean response rate.

The family of functions in the upper panel are trend lines (plotted by eye) of the group mean of the median RTs, with sucrose as the parameter. The lower panel presents trend lines (plotted by eye) of the group mean of the median response rates, with sucrose as the parameter.

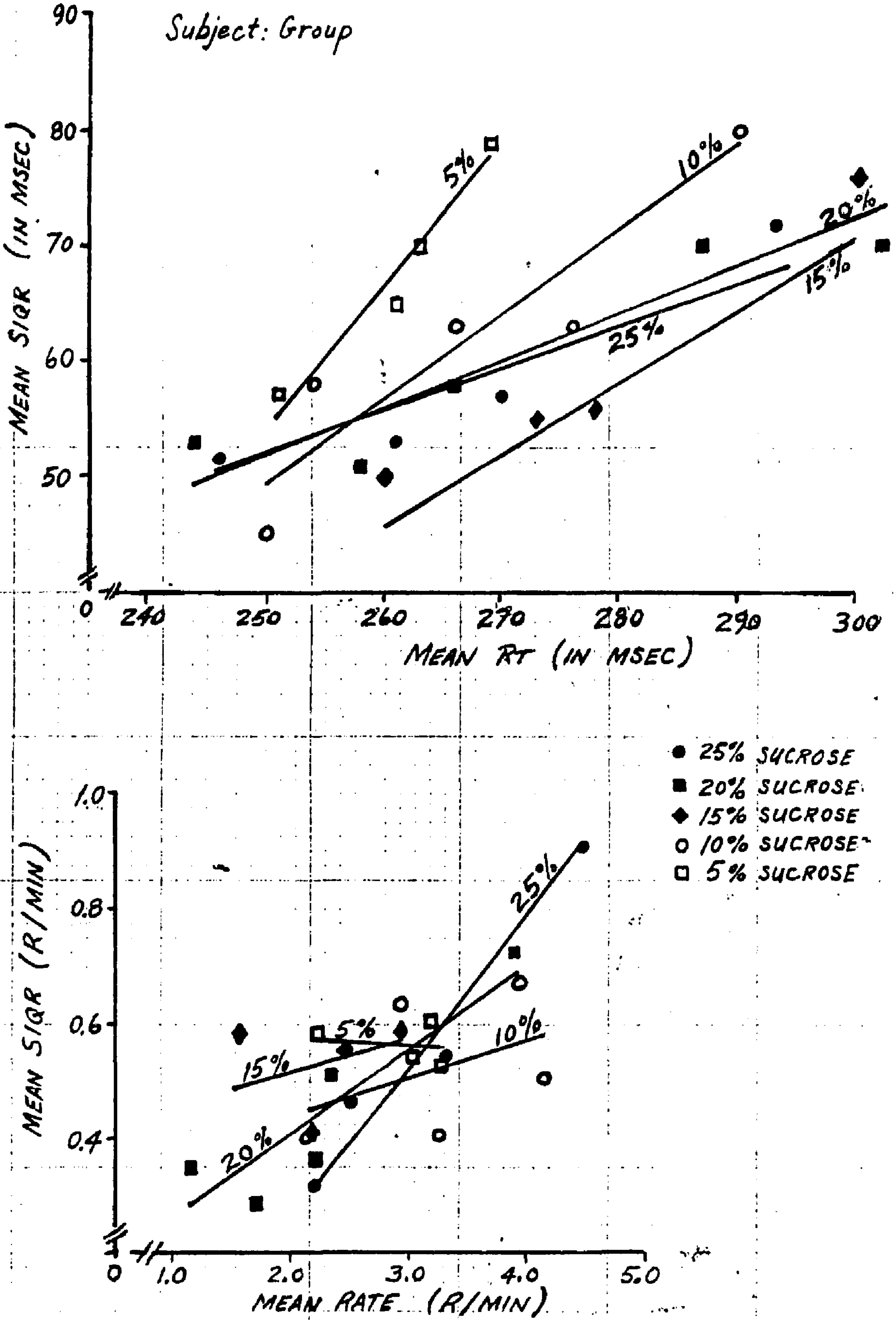
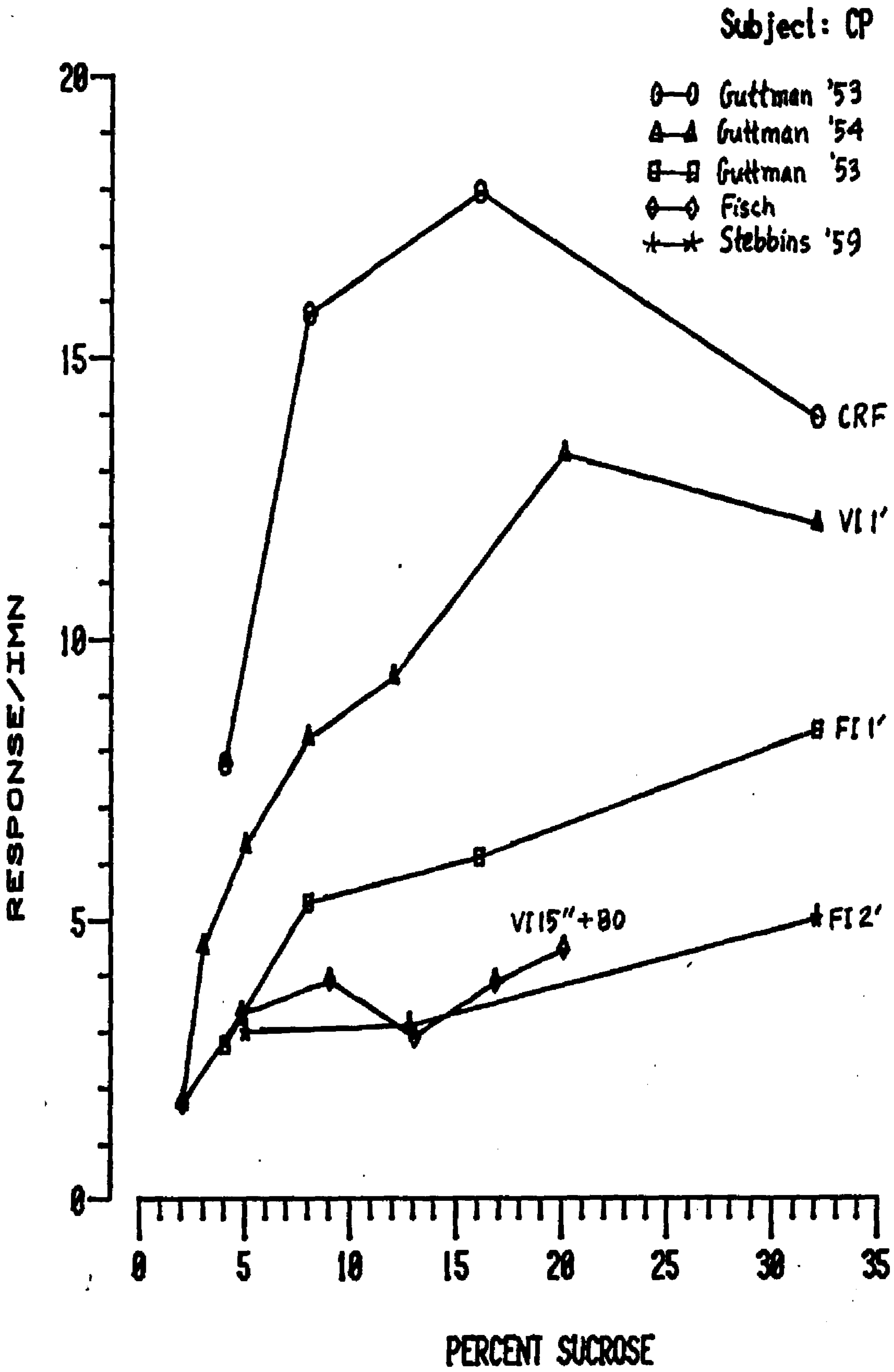

Subject: Group
MEAN SIQR (IN MSEC)
90
80
70
60
50
0
240
250
260
270
280
290
300
MEAN RT (IN MSEC)
5%
10%
20%
15%
25%
● 25% SUCROSE
■ 20% SUCROSE
◆ 15% SUCROSE
○ 10% SUCROSE
□ 5% SUCROSE
MEAN SIQR (R/MIN)
1.0
0.8
0.6
0.4
0
1.0
2.0
3.0
4.0
5.0
MEAN RATE (R/MIN)
25%
5%
10%
15%
20%

Figure 7. Comparison of group response rates with earlier studies.

This figure shows group response rate data from this study in comparison with rate data obtained by previous investigators, i.e. Guttman (1953; 1954); and Stebbins, et al (1959).


Subject: CP
Guttman '53
Guttman '54
Guttman '53
Fisch
Stebbins '59
CRF
VI 1'
FI 1'
VI 15"+80
FI 2'
RESPONSE/IMN
PERCENT SUCROSE
0
5
10
15
20
25
30
35

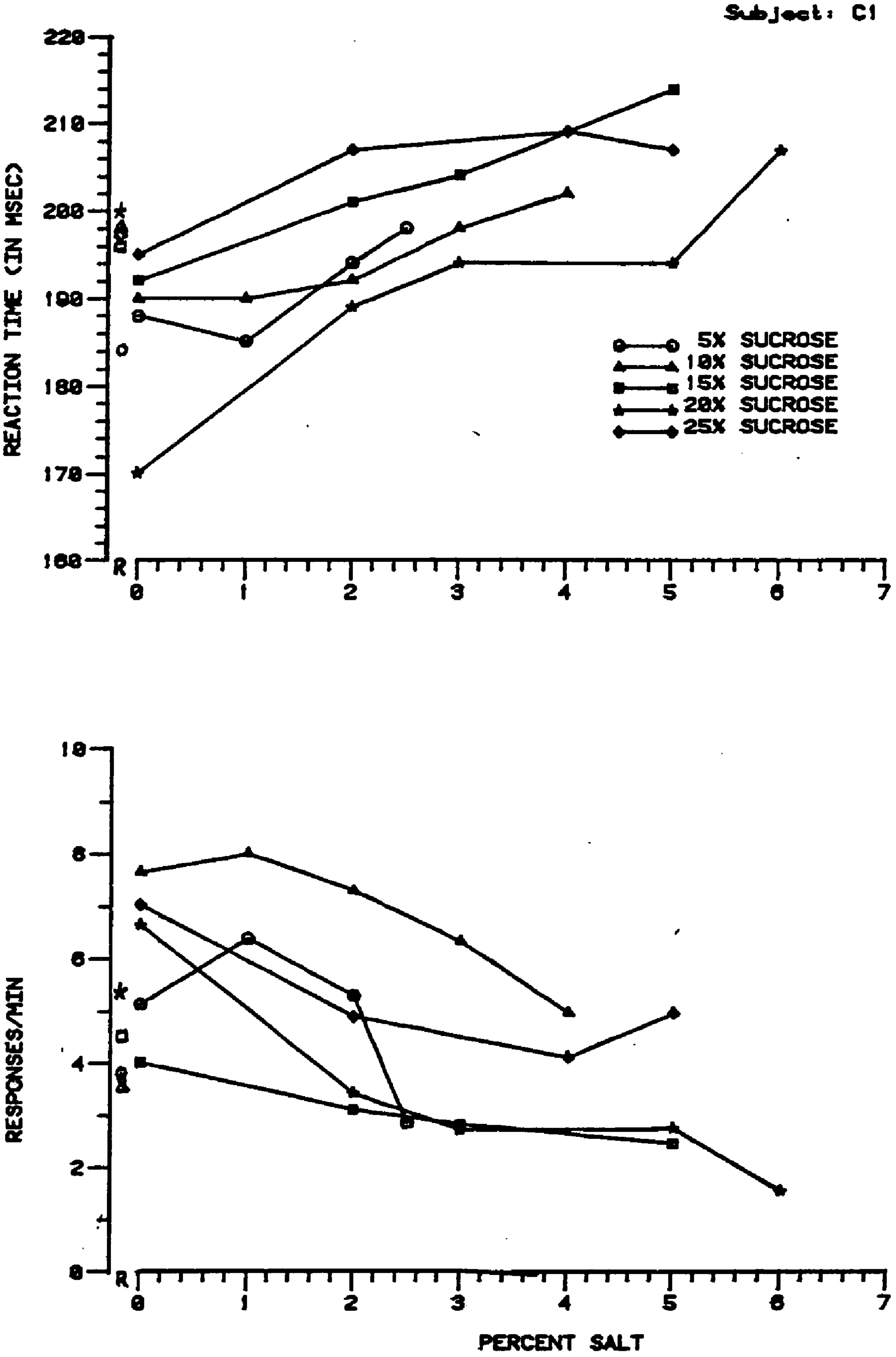
by weight was obtained by dividing the weight of the solute by the sum of the weight of the solute and the weight of the solvent, the fraction of which is multiplied by 100. In order to make the data from this study comparable, the same procedure was applied here. The transformed sucrose concentrations were: 2%, 4.8%, 9.1%, 13%, 16.7%, and 20%. The results, in general, indicate that response rates increase as a function of increasing amounts of sucrose.

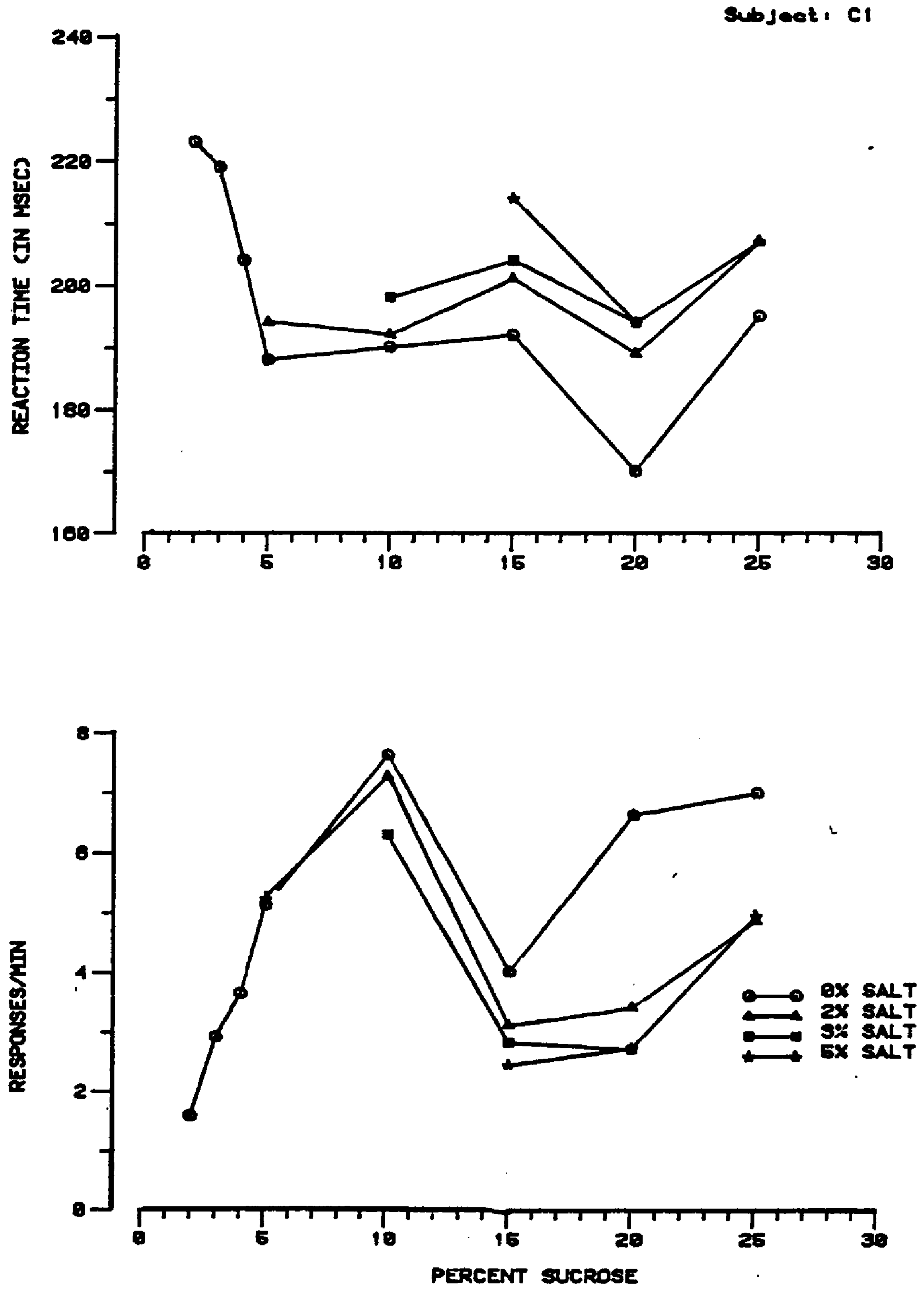
The data for individual subjects (C1, C2, C4, C5, C6, C8, and C9) are presented in Figures 8 through 21 inclusive. In many respects, the data for C1, C2, C8 and C6 (presented in Figures 8 to 15) are most reflective of the group data. It should be noted that rats C1, C2, and C8 received 6 months more training than the other subjects.

The data for C1 are shown in Figures 8 and 9. Figure 8 depicts a family of functions in which sucrose is the parameter and salt is the independent variable. The dependent variables are median RT in milliseconds (upper panel) and median response rate in r/min (lower panel). The RT functions resemble the group data in several respects: they are roughly parallel to one another over the range of salt values; and the median RT increases as the amount of salt is increased. They differ in that the gradients for C1 are flatter than those for the group data. In fact, the slope of the

Figures 8. to 21. Median RTs and response rates for individual subjects.

This sequence of figures depicts median RTs (upper panels) and median response rates (lower panels) for individual subjects. Pairs of figures are presented for each subject. The first figure in each pair shows sucrose as the parameter and salt as the independent measure. The second figure in the pair shows salt as the parameter and sucrose as the independent measure. Figures 8 and 9 present the data for subject C1; figures 10 and 11 represent the data for C2; figures 12 and 13 are the data for C8; figures 14 and 15 are for C6; figures 16 and 17 are for C4; figures 18 and 19 are for C9; and figures 20 and 21 are for C5.


Subject: C1
REACTION TIME (IN MSEC)
220
210
200
190
180
170
160
R
0
1
2
3
4
5
6
7
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE
RESPONSES/MIN
10
8
6
4
2
0
R
0
1
2
3
4
5
6
7
PERCENT SALT


Subject: C1
REACTION TIME (IN MSEC)
240
220
200
180
160
0
5
10
15
20
25
30
RESPONSES/MIN
8
6
4
2
0
0
5
10
15
20
25
30
PERCENT SUCROSE
0% SALT
2% SALT
3% SALT
5% SALT

family of functions for C1 is decreasing as salt values increase; whereas in the group data, the slopes of the functions increase for increasing salt values.

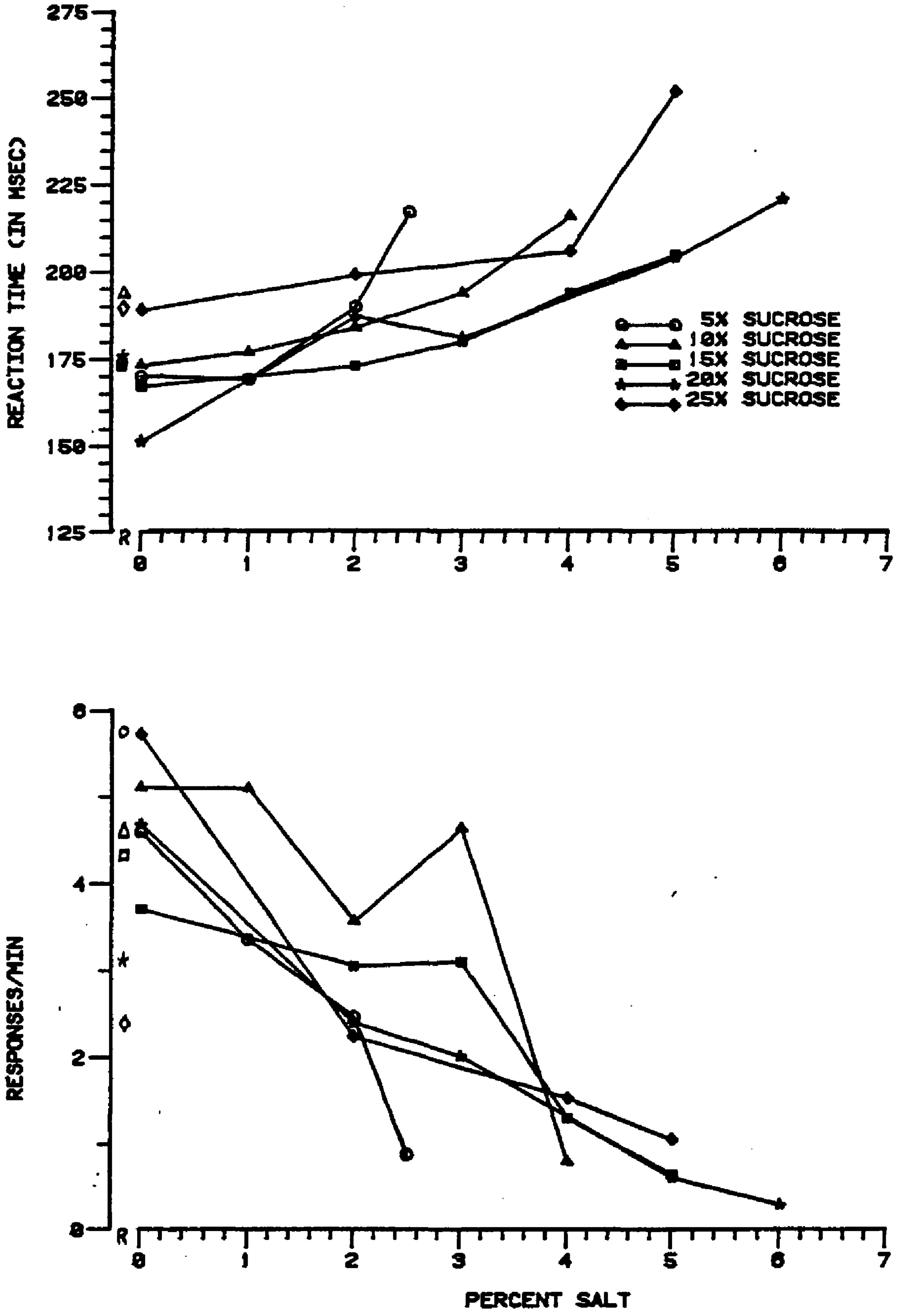
The rate functions for C1 are similar to the group rate functions in that they both indicate that as salt concentration is increased, response rate decreases. However, the family of functions for C1 adheres less to the trend established for the group data. In addition, there are several reversals in rate.

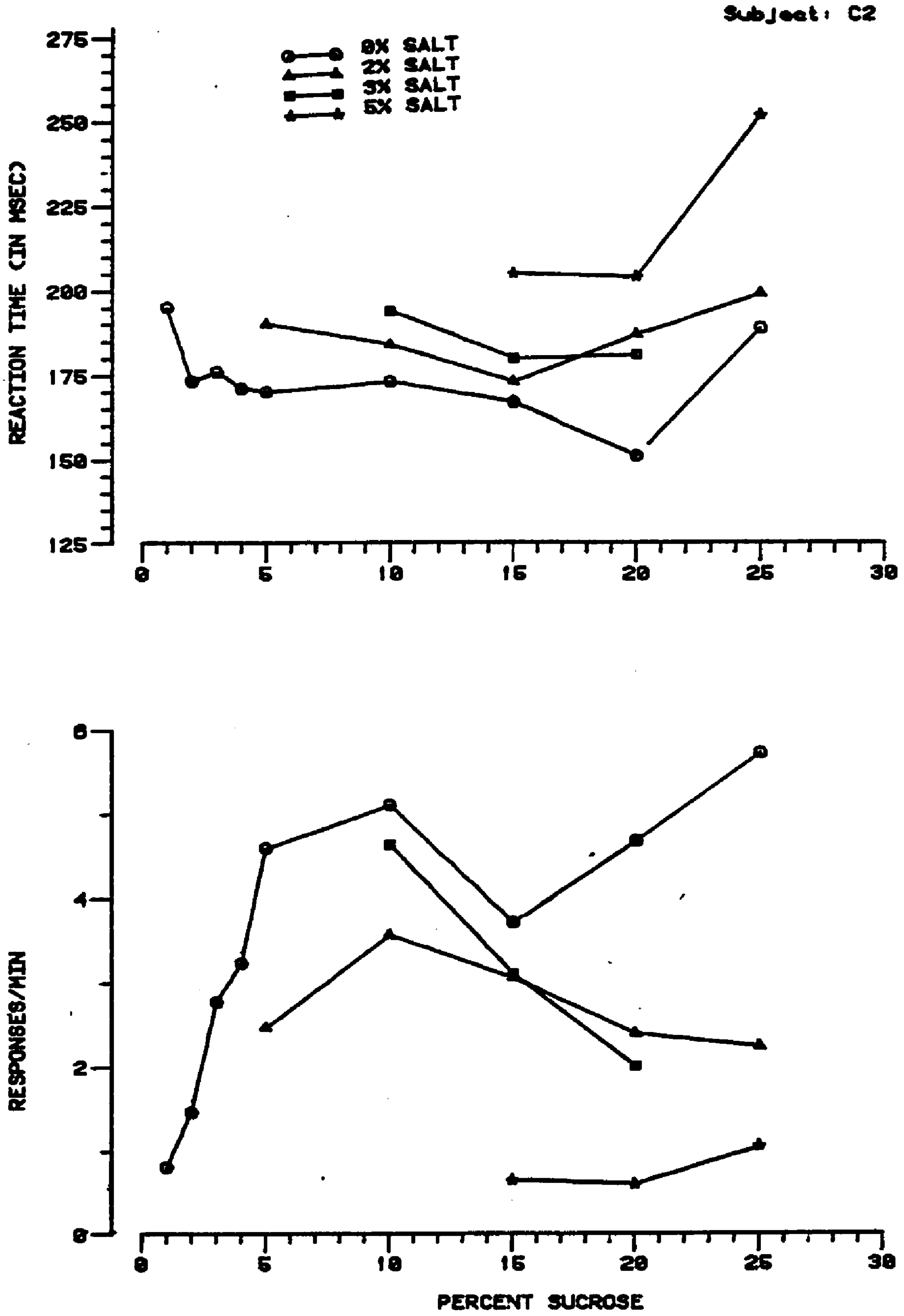
Figure 9 presents the family of functions for C1 plotted with salt concentration as the parameter and sucrose concentration as the independent variable. Like the two families of functions for the group data, the functions for C1 are non-monotonic. Both families of functions are totally ordered for the salt parameter.

In order to avoid repetition in presenting data for the remaining subjects, the figures presented for each follow the format adopted for C1 and for the group. Namely, a pair of figures for each subject will be presented. The upper panel in both figures will show RT functions, while the lower panel will show rate functions. The first figure will indicate sucrose as parameters and salt as the independent variable, while the second will indicate salt as parameters and sucrose as the independent variable.

The data for C2 are presented in Figures 10 and 11. For this subject, the family of functions in which RT is

Subject: C2


REACTION TIME (IN MSEC)
275
250
225
200
175
150
125
R
0
1
2
3
4
5
6
7
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE
RESPONSES/MIN
6
4
2
0
R
0
1
2
3
4
5
6
7
PERCENT SALT


Subject: C2
0% SALT
2% SALT
3% SALT
5% SALT
REACTION TIME (IN MSEC)
275
250
225
200
175
150
125
0
5
10
15
20
25
30
RESPONSES/MIN
6
4
2
0
0
5
10
15
20
25
30
PERCENT SUCROSE

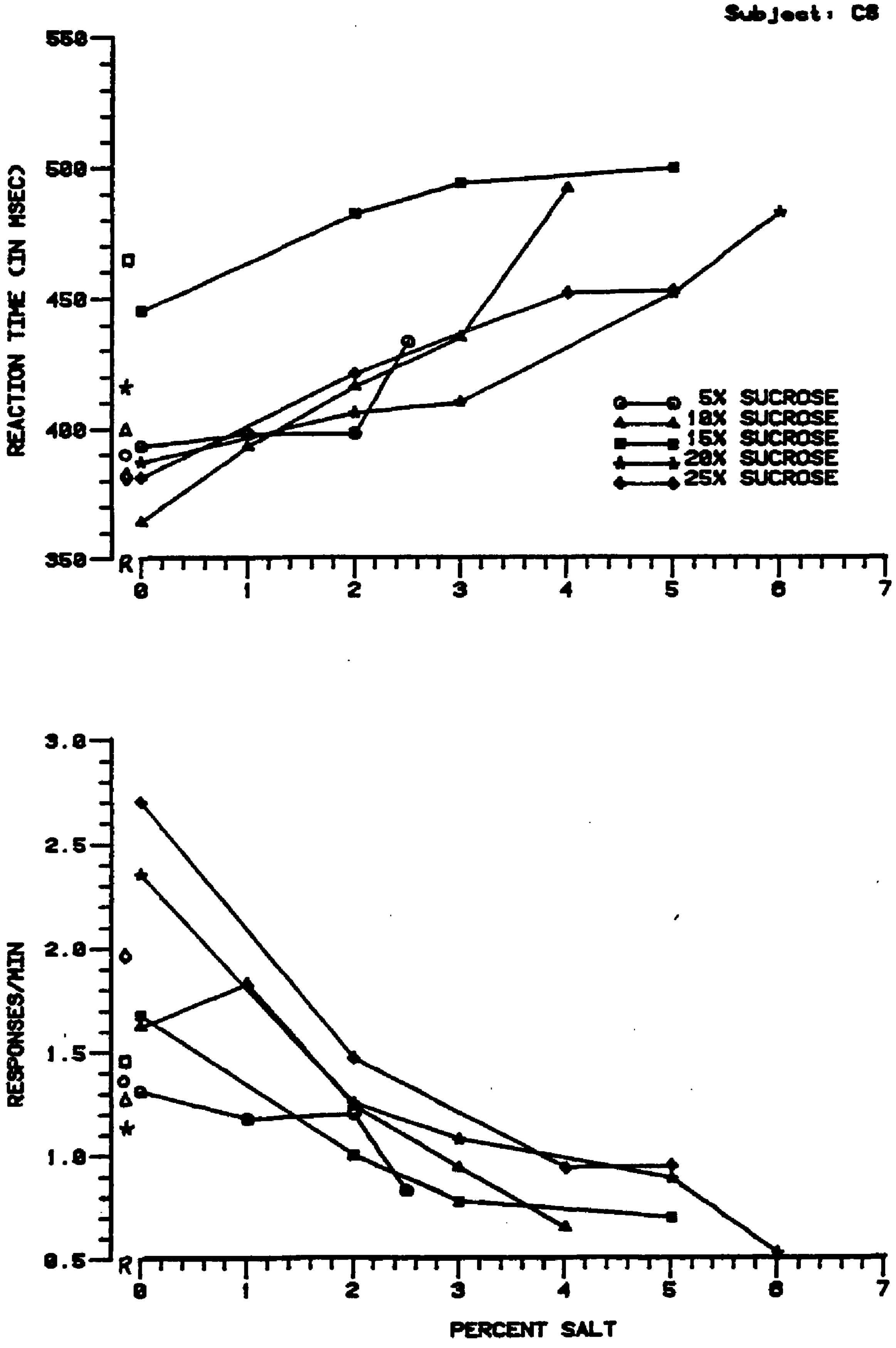
the dependent variable is not unlike that of the group. The family of functions for C2 is not totally ordered either, as was the case with C1 several functions frequently intersect each other. The gradients for these functions are steeper than are those for the group.

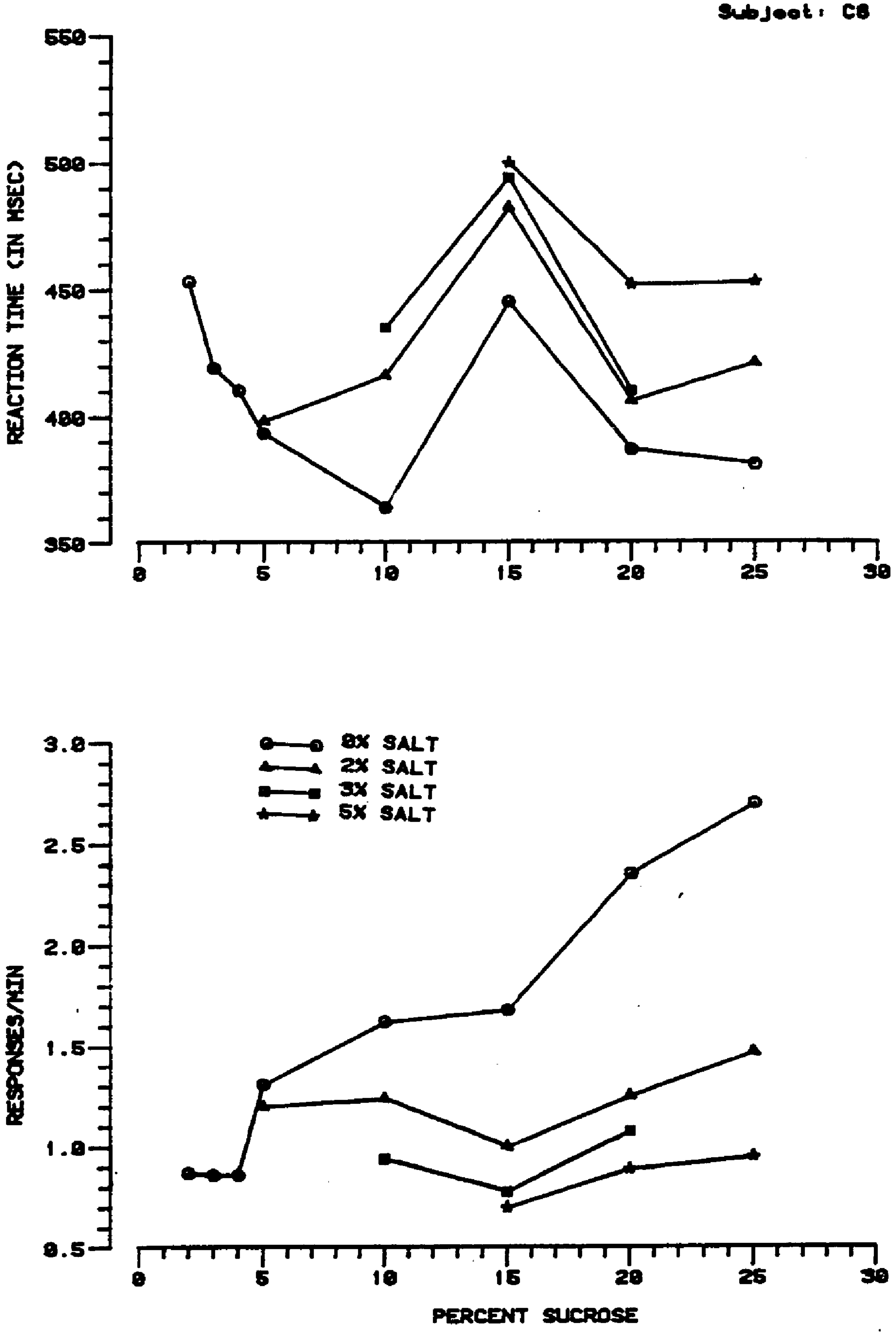
The family of functions for C2 in which response rate is the dependent measure is more consistent with the group data functions. The trend for the functions is the same as salt is increased, response rate declines. The family of functions for C2 is also similar to those of the group: as salt concentration is increased, the family of functions converges.

In Figure 11, functions in the upper panel are similar to those for C1 in Figure 9. Both families of functions are non-monotonic, and they show increasing RT with increasing salt concentration. For values of sucrose below 20%, as concentration is decreased, RT increases.

The family of functions in the lower panel of Figure 11 also resemble the comparable group functions, but are only partially ordered for salt parameters.

The data for C8 are shown in Figures 12 and 13. In Figure 12, the effect of increased concentrations of salt on RT is the same for C8 as for C1, C2, and the group data. It is, however, most pronounced for this


Subject: CS
REACTION TIME (IN MSEC)
550
500
450
400
350
R
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE
0
1
2
3
4
5
6
7
RESPONSES/MIN
3.0
2.5
2.0
1.5
1.0
0.5
R
0
1
2
3
4
5
6
7
PERCENT SALT


Subject: C8
REACTION TIME (IN MSEC)
550
500
450
400
350
0
5
10
15
20
25
30
RESPONSES/MIN
3.0
2.5
2.0
1.5
1.0
0.5
0X SALT
2X SALT
3X SALT
5X SALT
PERCENT SUCROSE

subject. The slopes for these functions are steeper than those for any other subject. Although four of the functions are clustered close together for salt concentrations between 0% and 2%, the 15% sucrose function is unusual in that it is shifted upward from the other functions by more than 80 msec.

By contrast, the family of rate functions (Figure 12, lower panel) shows them overlapping one another. As with the group functions, response rate decreases as salt concentration is increased. The slope for the family of functions for C8 are more gradual than those for the group data. Moreover, the response rates are much lower for C8 than for the group over the entire range of salt values.

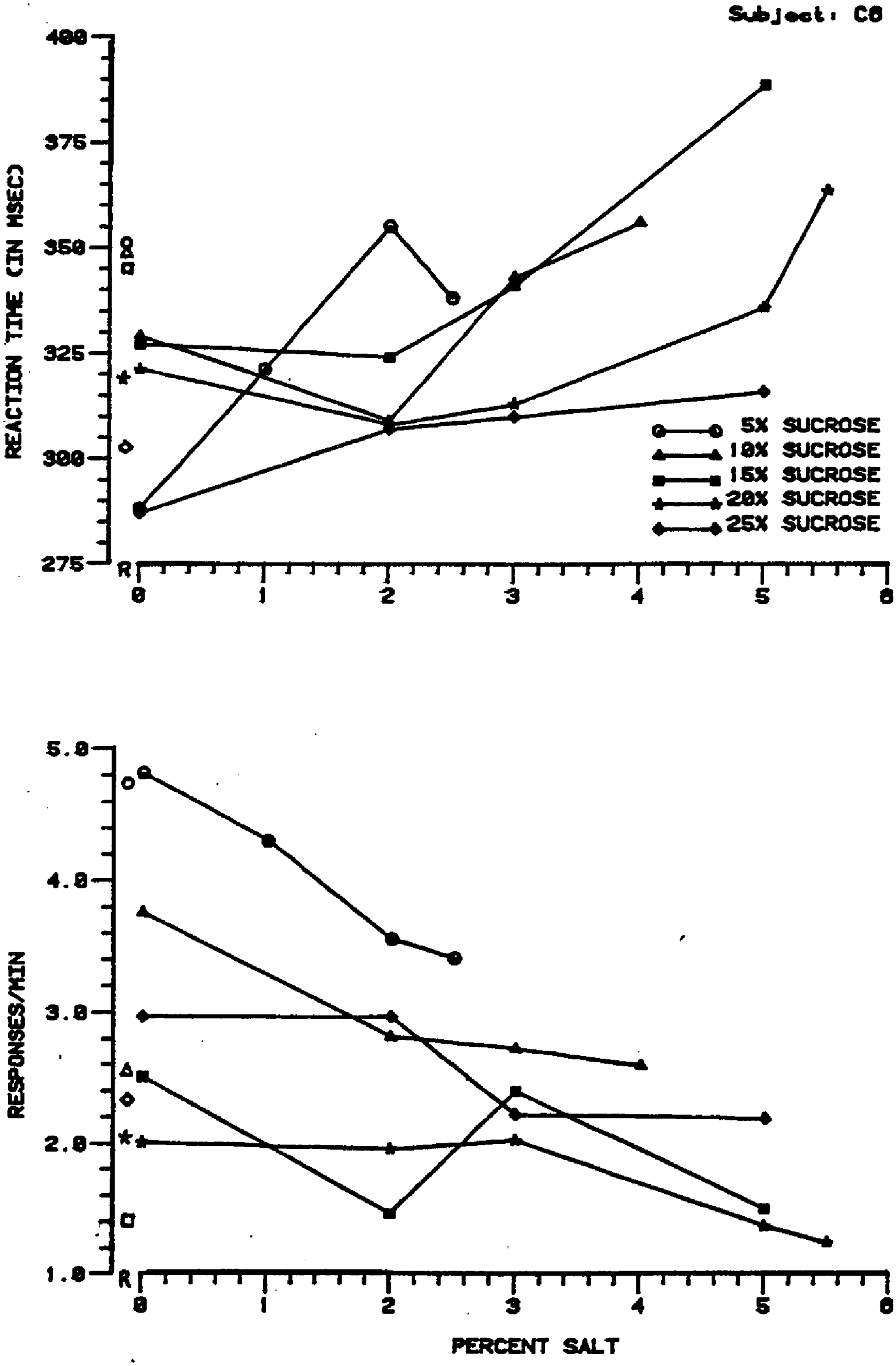
The unusually long RT for all values of salt at 15% sucrose concentration seen in Figure 12 is observed again in the upper panel of Figure 13. The elevated RT at the 15% sucrose parameter for the group data functions shown in Figure 3 can be attributed largely to the long reaction times for C8 at this value. Note, however, that the family of functions for C8 retains the total ordering for the salt parameter previously observed in subjects C1 and C2, and in the group functions. Also, for concentrations of sucrose below 15% at the 0% salt parameter, RT increases as sucrose concentration is decreased.

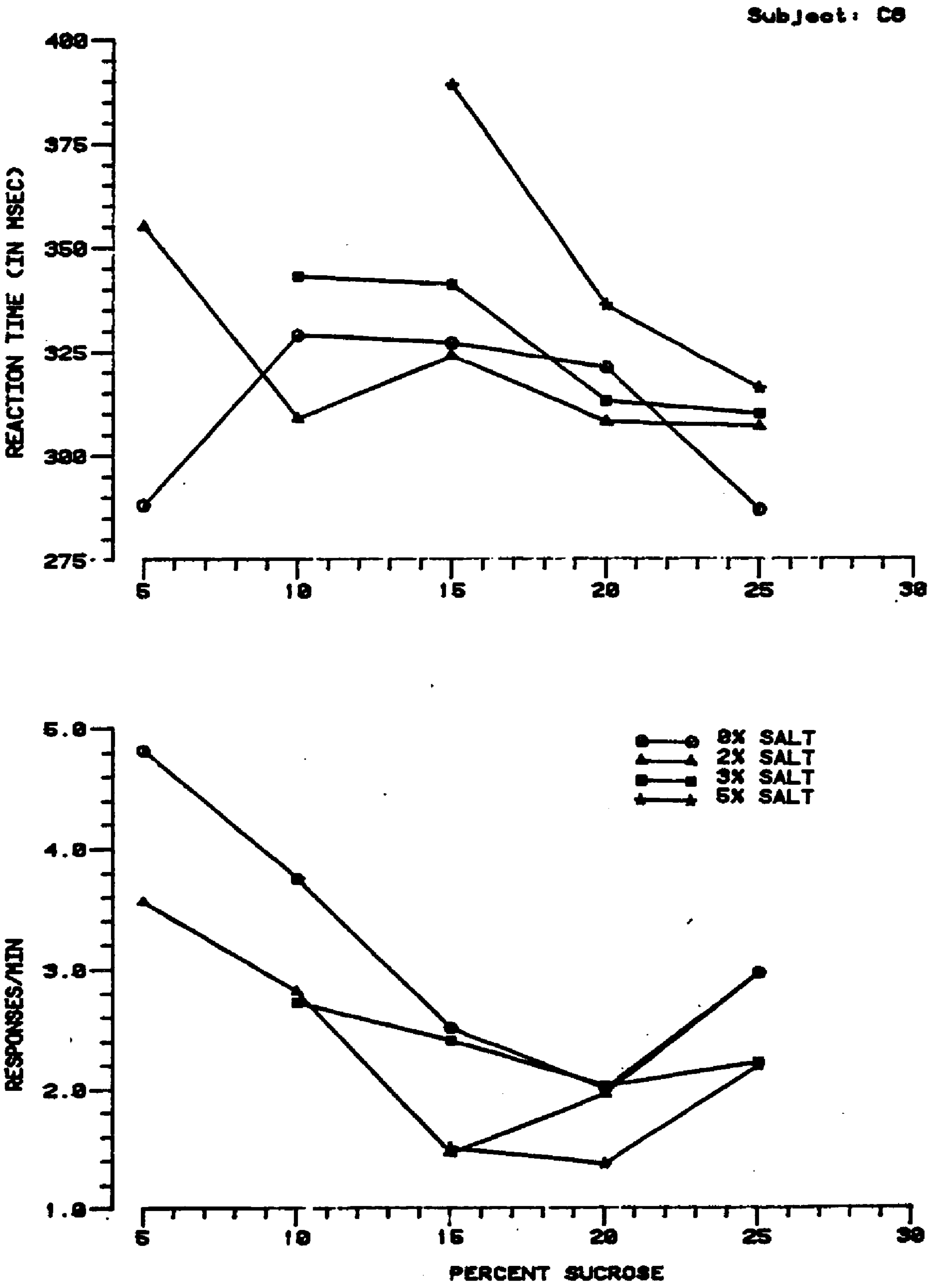
Total ordering is also found where response rate is the dependent variable (Figure 13, lower panel). Moreover, the response rate increases as sucrose concentration is increased at the 0% salt parameter. Unlike the group data, the functions in this family show a smaller rate difference from one to the other.

Figures 14 and 15 show the data for C6. For this subject, the effect of increased concentrations of salt is generally an increase in RT. The trend, however, is non-monotonic. There are two reversals; and the functions intersect one another at several points.

As for the rate measure (Figure 14, lower panel) the functions for C6 most resemble the group functions in Figure 2. Also, these functions converge onto one another as salt concentration is increased to its largest value. However, the highest rate for C6 is recorded at the 5% sucrose parameter; whereas the highest rate for the group is recorded at 25% sucrose.

The RT functions for C6 shown in Figure 15 (upper panel) are ordered for the 2%, 3%, and 5% salt parameters. The 0% salt function is atypical for the family. Although it is non-monotonic, it is also U-shaped and concave downward for increasing concentrations of sucrose. Except for the median RT at 5% sucrose, 0% salt, and for 15% sucrose, 2% salt, the trend is for RT to decrease as sucrose concentration is increased. Furthermore, the family of rate functions


Subject: C6
400
375
350
325
300
275
REACTION TIME (IN MSEC)
R
0
1
2
3
4
5
6
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE
5.0
4.0
3.0
2.0
1.0
RESPONSES/MIN
R
0
1
2
3
4
5
6
PERCENT SALT

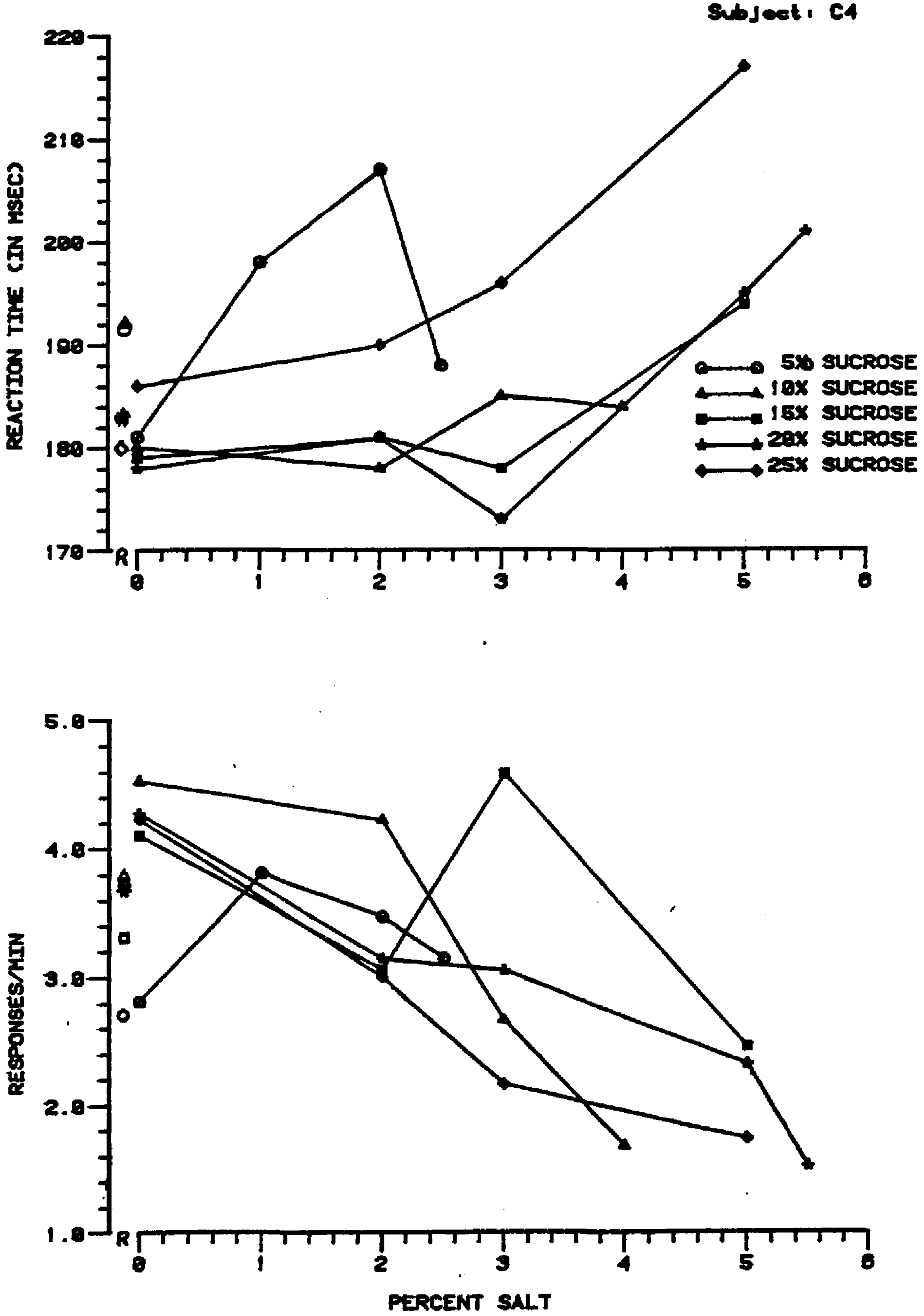

Subject: C8
REACTION TIME (IN MSEC)
400
375
350
325
300
275
5
10
15
20
25
30
RESPONSES/MIN
5.0
4.0
3.0
2.0
1.0
0% SALT
2% SALT
3% SALT
5% SALT
5
10
15
20
25
30
PERCENT SUCROSE

(Figure 15, lower panel) also depict a partial order effect for the salt parameters. Here too, although the family of functions is non-monotonic, response rate tends to decrease as sucrose concentration is increased.

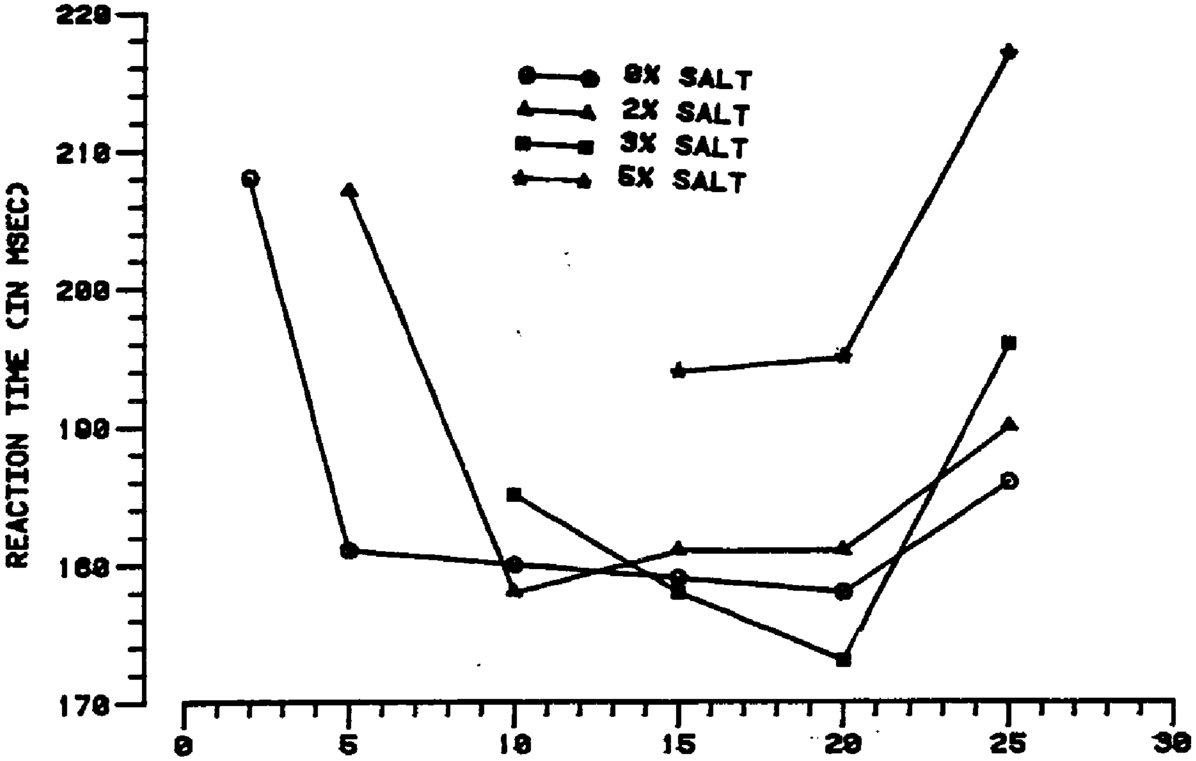
The data for C4 are presented in Figures 16 and 17. The family of RT functions (Figure 16, upper panel) is nearly consonant with the findings previously obtained for other subjects. There are several reversals in median RT, but they fall within the SIQR. For example, the shortest median RT (173 msec at 20% sucrose, 3% salt) has a SIQR of 43 msec, whereas the median RT recorded at 20% sucrose, 0% salt was 178 msec, with a 51 msec SIQR. Three sucrose functions (10%, 15%, and 20%) overlap one another over the range of salt values.

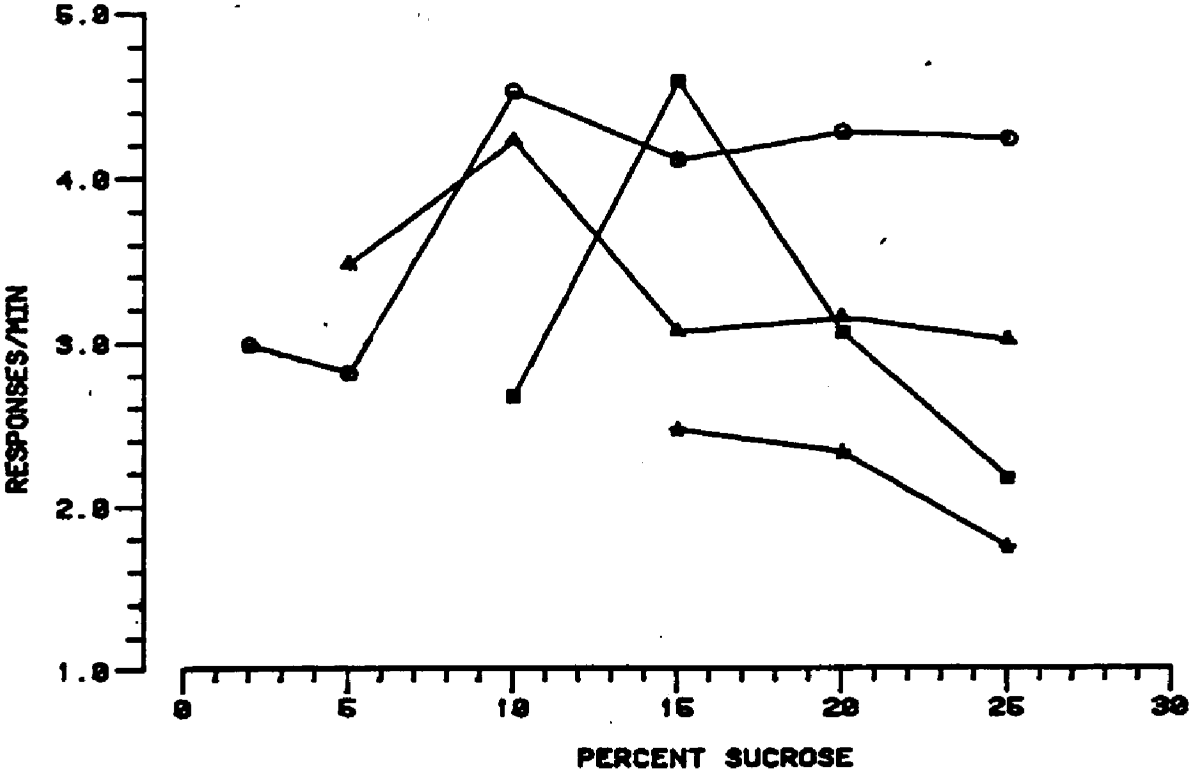
The trend for the family of rate functions for C4 (Figure 16, lower panel) is roughly decreasing as salt concentration is increased. The family of functions for C4 in Figure 17 differs somewhat from the group functions, although the RT functions (upper panel) are similar to those for subjects C1 and C2. The functions at three of the salt parameters (0%, 2%, and 3%) resemble one another, but are not ordered for salt. The function at 5% salt yielded longer RT's than the lower salt values. At the lowest concentration of sucrose, for 0% salt, RT is longer than at higher concentrations of sucrose.

The lower panel of Figure 17 shows the family of


Subject: C4
REACTION TIME (IN MSEC)
220
210
200
190
180
170
R
0
1
2
3
4
5
6
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE
RESPONSES/MIN
5.0
4.0
3.0
2.0
1.0
R
0
1
2
3
4
5
6
PERCENT SALT

Subject: C4

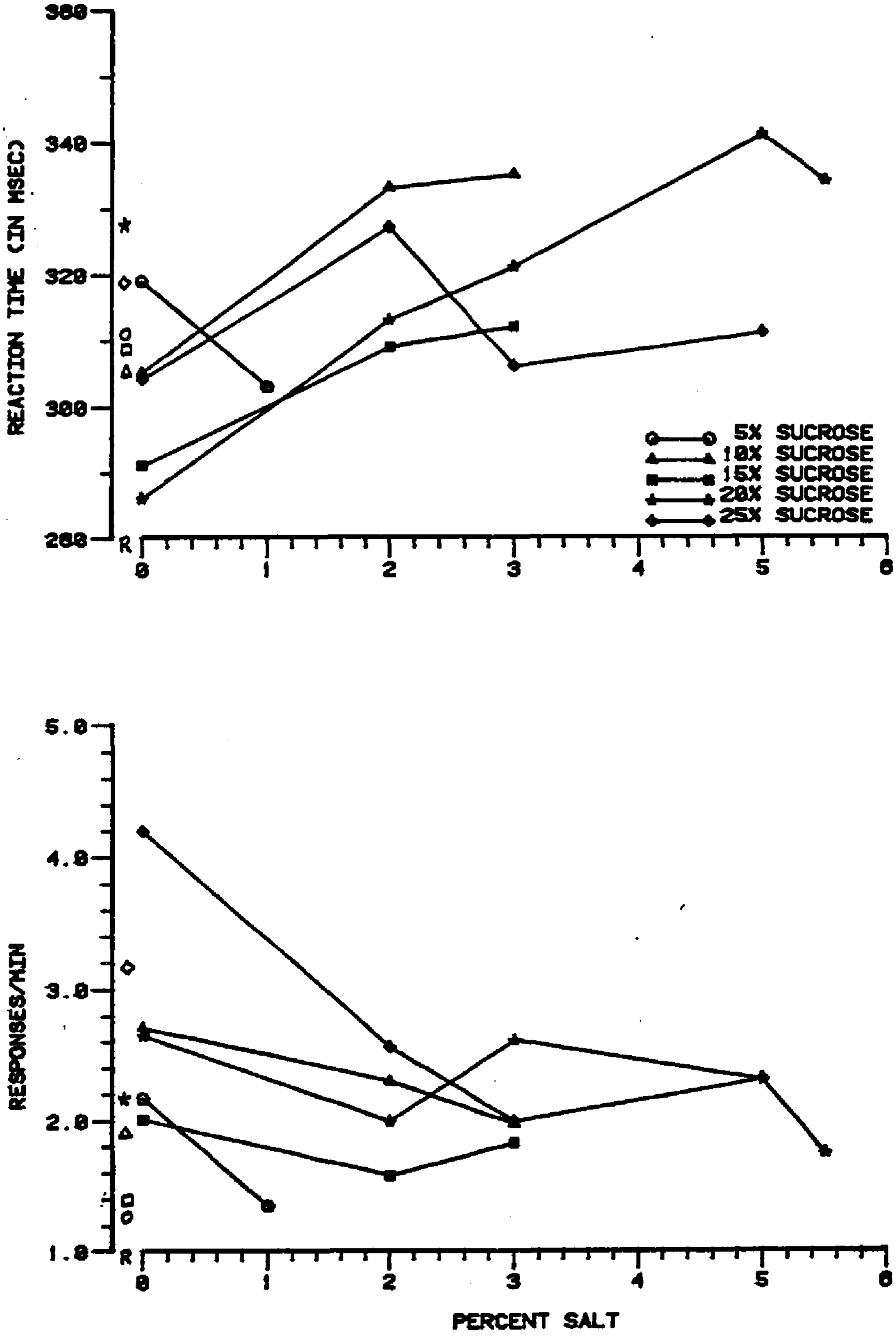

0% SALT
2% SALT
3% SALT
5% SALT
REACTION TIME (IN MSEC)
220
210
200
190
180
170
0
5
10
15
20
25
30

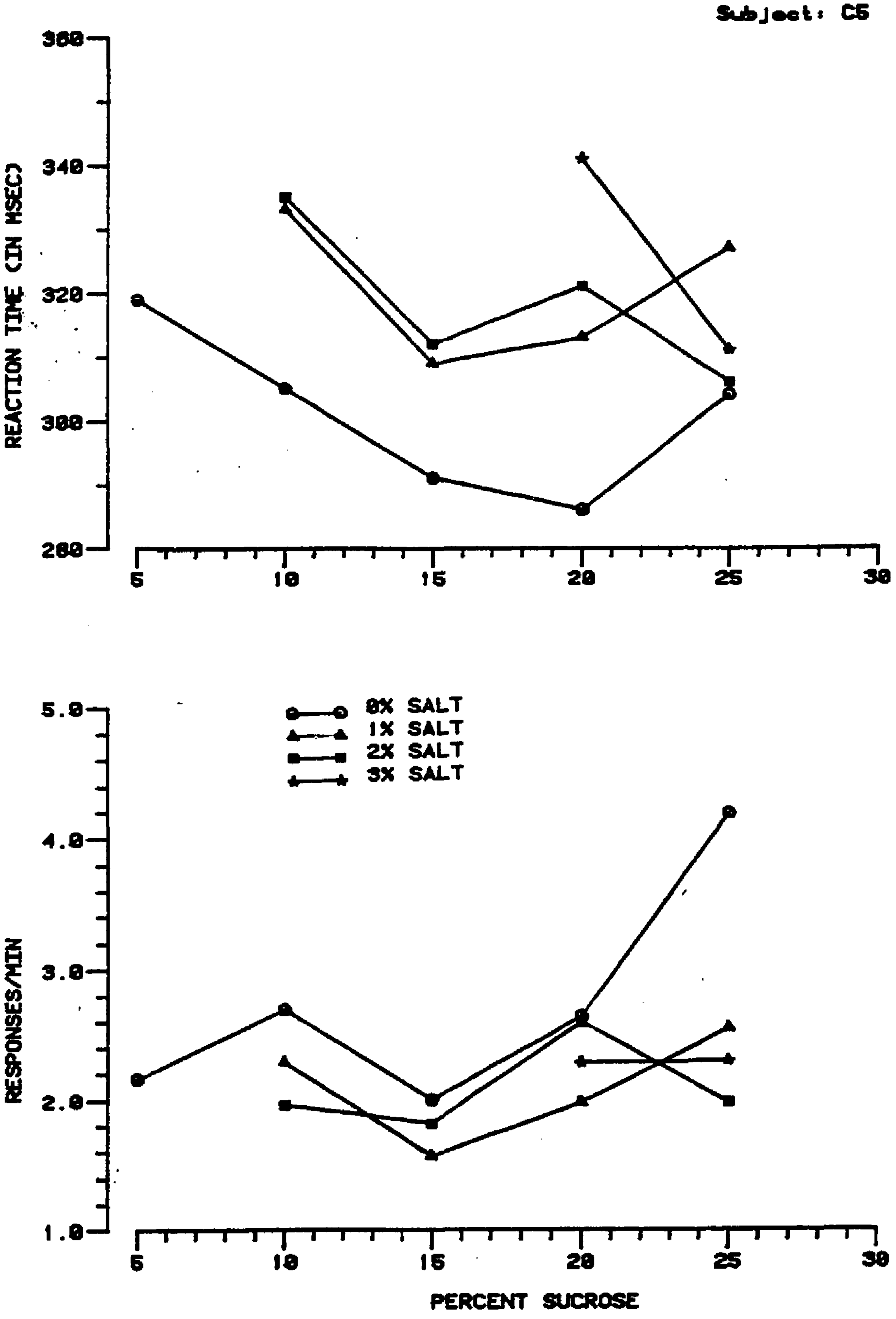

RESPONSES/MIN
5.0
4.0
3.0
2.0
1.0
0
5
10
15
20
25
30
PERCENT SUCROSE

functions to be only partially ordered. There is a large rate reversal at 15% sucrose, 3% salt. The function for that salt parameter intersects two other functions. There is no strong trend in this family of functions, although it may be argued that, at 0% salt, rate is greater at higher sucrose concentrations than at lower ones. The SIQR at 5% sucrose 0.27 r/min, whereas the SIQR at 20% sucrose is 0.46 r/min.

The data for subject C5 are presented in Figures 18 and 19. In terms of direction, the slopes for the RT functions are about the same as those for the group. Although the trend is for longer RT's given higher concentrations of salt, there are several reversals. In the lower panel, the functions illustrate declining response rates for increased salt concentrations, although the slopes of these functions are less steep than those for the group.

In Figure 19, there appears a partial order in the family of RT functions, despite two reversals at the highest concentration of sucrose. Clearly, the function at the 0% sucrose parameter has the shortest RT for this family. The two reversals at 25% sucrose the rate functions (lower panel) lack order for the salt paraeters. These functions are non-monotonic, but at the 0% salt parameter, the trend for rate is an increasing one as sucrose concentration is increased.

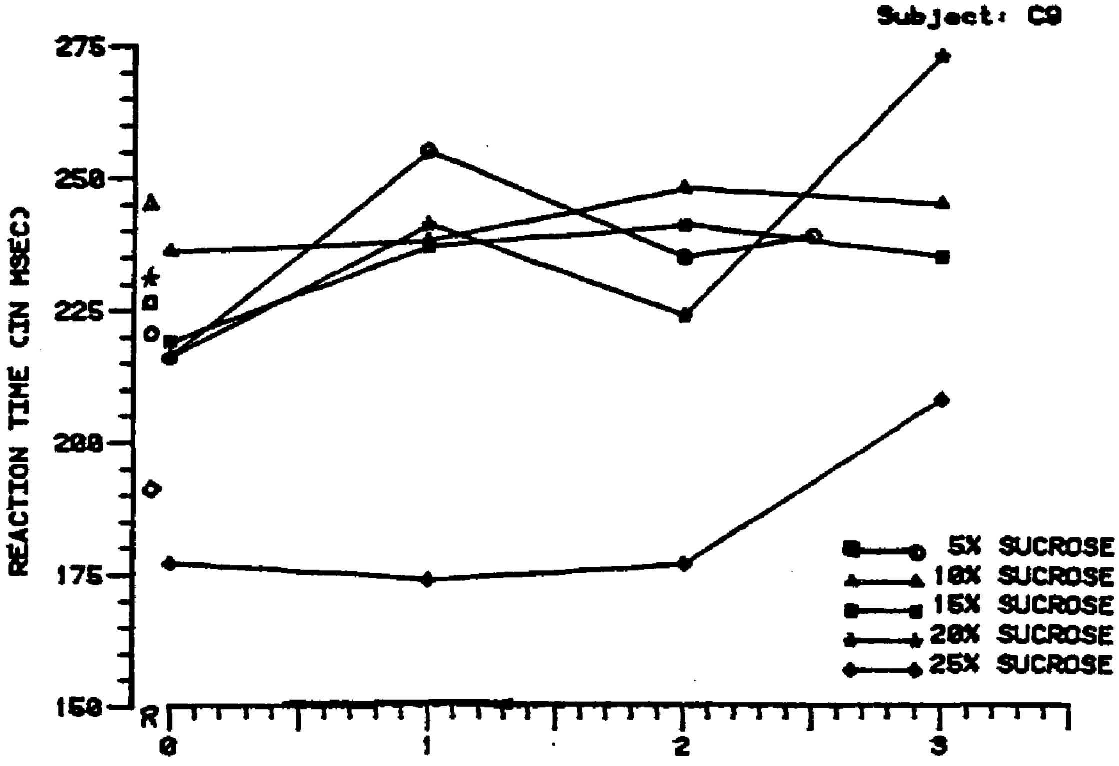

Subject: C5
360
340
320
300
280
REACTION TIME (IN MSEC)
R
0
1
2
3
4
5
6
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE
5.0
4.0
3.0
2.0
1.0
RESPONSES/MIN
PERCENT SALT

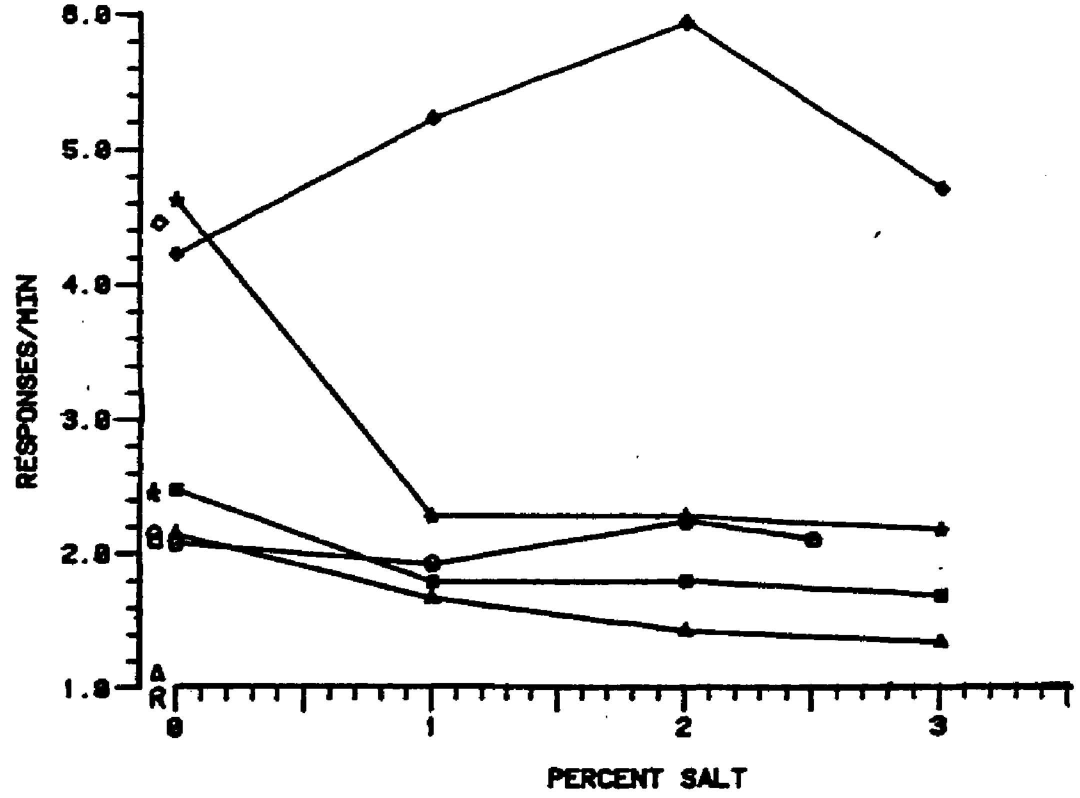

Subject: C5
REACTION TIME (IN MSEC)
360
340
320
300
280
5
10
15
20
25
30
RESPONSES/MIN
5.0
4.0
3.0
2.0
1.0
0% SALT
1% SALT
2% SALT
3% SALT
5
10
15
20
25
30
PERCENT SUCROSE

Figures 20 and 21 present families of functions for C9. The trend in the RT functions (upper panel) is only clear for the 25% sucrose parameter, where RT increases at the 3% salt concentration. the remaining functions are bunched together within the SIQR's of these median RT's, and there are several RT reversals among them. The slopes for these functions are relatively flat.

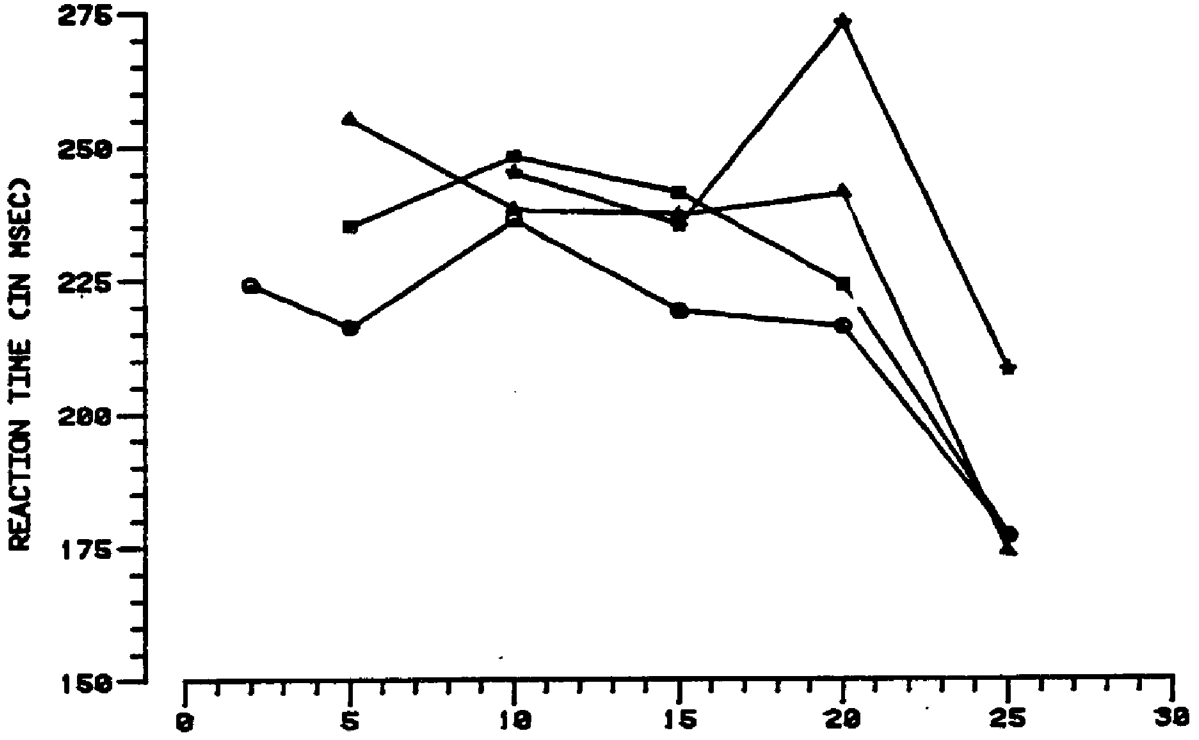
In the lower panel, the trend for response rate is in the same direction as the group functions, but the slopes are flatter. All sucrose parameters, except for 25%, illustrate this declining trend. This subject was unusual in that he could not tolerate more than 3% salt at any sucrose parameter.

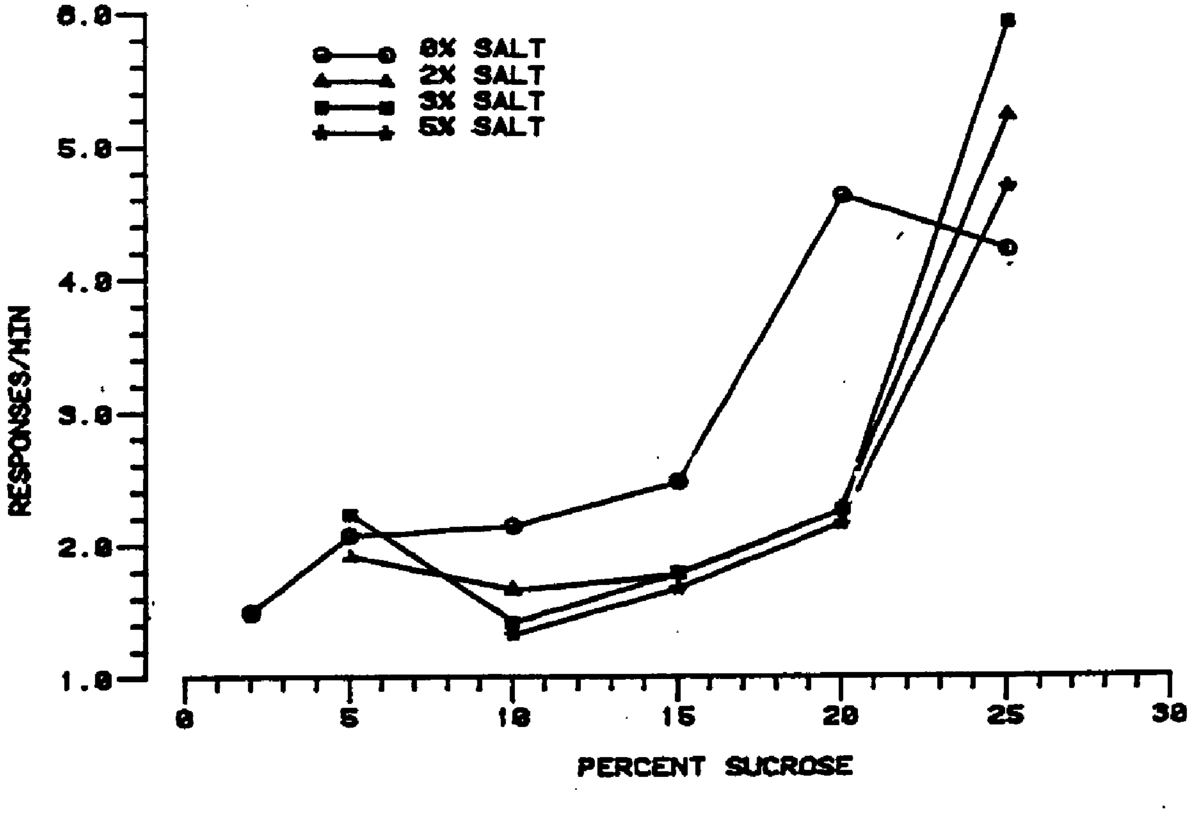
In the upper panel of Figure 21, RT decreases as sucrose concention is increased from 20% to 25%. The family of functions in the lower panel appear partially ordered for the salt parameters. The trend is an increasing one for response rate as sucrose concentration is increased.


Subject: C9
REACTION TIME (IN MSEC)
275
250
225
200
175
150
R
0
1
2
3
5% SUCROSE
10% SUCROSE
15% SUCROSE
20% SUCROSE
25% SUCROSE


RESPONSES/MIN
6.0
5.0
4.0
3.0
2.0
1.0
A
R
0
1
2
3
PERCENT SALT

Subject: C9


REACTION TIME (IN MSEC)
275
250
225
200
175
150
0
5
10
15
20
25
30


RESPONSES/MIN
6.0
5.0
4.0
3.0
2.0
1.0
0X SALT
2X SALT
3X SALT
5X SALT
0
5
10
15
20
25
30
PERCENT SUCROSE

Discussion

In elaborating the findings, the focus will be primarily on how each of the response measures has been affected by the parameters of sucrose and salt. RT as a function of sucrose concentration is considered first. These data are contrasted with the findings obtained by Stebbins. Rate as a function of sucrose concentration is examined next and compared with the findings obtained by Guttman and others. The effect of salt concentration on both RT and rate are then investigated and compared with the findings obtained by Young and his colleagues. The application of indifference functions to these data as a means for determining relative preference is also examined. Finally, these data are analyzed to determine if there is a relationship between the two response measures.

RT as a function of sucrose concentration

Earlier studies (Stebbins & Lanson, 1961; Stebbins, 1962) have shown that the reaction time of a discriminative operant is a function of several parameters; schedule of reinforcement and amount of reinforcement among others. In particular, Stebbins (1962) found a marked increase in median RT as a result of a decrease in amount of reinforcement. Both median RT and variability (semiinterquartile range) increased when the concentration of sucrose was decreased from 20%

to 0%, or from 20% to 5%. Moreover, the change in the median RT and SIQR was greater when sucrose concentration was decreased from 20% to 0%, than when sucrose concentration was decreased from 20% to 5%.

The findings in the present study resulted from a different measure of percent concentration by weight than the one recommended by Pfaffmann, et al (1954) and employed by Stebbins and Guttman. Tucker (1978), however, has indicated that all of these techniques are acceptable. Given the available equipment, it was simpler to measure percent concentration by the technique described elsewhere. However, in order to compare the data reported by Stebbins and Guttman to those from the present study, the percent concentration by weight in this study was transformed according to the above method. Thus, a 25% concentration here was transformed to 20%; a 5% concentration became 4.8%. A shift from a 25% sucrose concentration to one at 5% in this study is comparable to the shift from 20% sucrose to 5% sucrose in the Stebbins study.

For the group data shown here in Figure 3, the median RT at 25% sucrose (0% salt) was 246 msec as opposed to 251 msec for 5% sucrose (0% salt). As for variability, the SIQR for the group data was 52 msec at 25% sucrose as opposed to 57 msec at 5% sucrose (cf. Figure 5, upper panel). In terms of direction, these data are consonant with Stebbins' findings. The difference in the median RT's in this study is within the range of intersubject variability.

The median RT and SIQR for individual subjects at 25% and at 5% sucrose is presented in Table 2. Subjects C5, C8, and C9 show marked increases in median RT at 5% sucrose as compared to their median RT at 25% sucrose. C1, C2, and C4 show decreases in RT for these sucrose values, and C6 shows no perceptible change. As for variability, five of the seven subjects (C4, C5, C6, C8, and C9) show increases in SIQR at 5% sucrose when these measures are compared with the variability at 25% sucrose.

Stebbins (1962) suggests that latency is inversely related to response rate in comparable situations in which rate is reinforced. If such were the case, then the shortest RT would be associated with that sucrose concentration for which the highest rate of responding were recorded. Likewise, the longest latency would be associated with that sucrose concentration for which the lowest response rate were recorded. Earlier, Guttman (1953) indicated that the lowest rate of responding under a schedule of regular reinforcement was recorded at the lowest concentration of sucrose (4%). Five subjects in this study were exposed to sucrose concentrations comparable to Guttman's 2% and 20% sucrose

Table 2: Median RT in msec and SIQR () for individual subjects,for sucrose concentrations of 25% and 5%.

% Sucrose	25	5
Subject		
C1	195(38)	188(29)
C2	189(40)	170(27)
C4	186(40)	181(50)
C5	304(55)	319(60)
C6	287(93)	288(120)
C8	381(59)	393(75)
C9	177(36)	216(40)

concentrations. The effect of changes in sucrose concentration on RT is more readily apparent for this group. GM median RT for a 20% sucrose concentration was 220 msec, as compared with a GM median RT of 256 msec at a 2% concentration. When measures of variability for this group are averaged and compared, the GM SIQR at 20% sucrose was 37 msec, whereas the GM SIQR at 2% sucrose was 47 msec. A t-test of differences in RT means at 2% and 20% sucrose indicated significance below .02.

The data for these individual subjects are compared in Table 3 (subjects C5 and C6 did not respond at 2% sucrose). All five subjects showed an increase in median RT at 2% sucrose, as compared with their median RT at 20% sucrose. With the exception of C9, four subjects showed a larger SIQR at 2% sucrose, as compared with 20% sucrose. Three of these four subjects (C1, C2, and C8) showed a 50% or greater increase in variability. These data support Stebbins' finding of increased variability as a function of decreasing sucrose concentration.

Rate as a function of sucrose concentration

Some investigators have used response rate to measure the effects of amount of reinforcement on behavior. Guttman (1953; 1954) found the relationship between amount of reinforcement (sucrose concentration) and rate of responding to be a non-monotonic

Table 3: Median RT in msec and SIQR () for individual subjects, for sucrose concentrations at 20% and 2%.

% Sucrose	20	2
subject		
C1	170(25)	223(37)
C2	151(20)	173(31)
C4	178(51)	208(57)
C8	387(36)	453(59)
C9	216(54)	224(51)

one for group data. Under a schedule of regular reinforcement, the response rate increased as sucrose concentration increased from 4% to 16%; the rate of responding then decreased for 32% sucrose. Under a schedule of aperiodic (VI 1') reinforcement, Guttman (1954) also found the relation between sucrose and response rate to be non-monotonic. The rate of responding increased as sucrose was increased from 4% to 20%. The rate then declined at 32% sucrose. On the other hand, Stebbins, Mead and Martin (1959) found a monotone increasing relation between response rate and logged sucrose concentrations from 5% to 50%. Stebbins attributed the semi-log function he obtained to the smallness of the dipper cup (.02 ml), although Guttman used a .005 ml cup in 1953 and a .01 ml cup in 1954.

The present findings also indicate a non-monotonic relation between rate and sucrose concentration for group data (see Figure 3, lower panel). The rate first increases as sucrose concentration is increased from 2% to 10%; then declines at 15%. This decrease exceeds the range of intersubject variability shown in Figure 5. The response rate then increases as sucrose concentration increased to 25%. The median response rate at 2% sucrose is 1.67 r/min (SIQR = 0.35); whereas the median rate at 25% sucrose is 4.43 r/min (SIQR = 0.91).

The present study is therefore generally consonant with previous findings (Guttman, 1953; 1954; Verhave, 1956) in which a non-monotonic increase in rate as a function of increasing sucrose concentration have been noted. The lower overall rate obtained here compared with rates from earlier studies may be attributed to the schedule of reinforcement and the penalty (BO) contingency. Variability in the rate of responding, as measured by the semi-interquartile range, is also a non-monotonic function of sucrose concentration (see Figure 5, lower panel). The GM SIQR is 0.30 r/min (s.d.= 0.27) at 2% sucrose, which increases to 0.68 r/min (s.d. = 0.47) at 10% sucrose. The variability declines to 0.59 r/min (s.d.= 0.21) at 15% sucrose, then continues to increase to a maximum value of 0.91 r/min (s.d.= 0.47) at 25% sucrose. A t-test of differences in rate means at 2% and 25% sucrose indicated a significance below .001. Thus, the SIQR for response rate is also affected by changes in the sucrose concentration.

The effect of salt on behavior

The present study confirms the effects of salt on behavior obtained by Pfaffmann (1960), Young (1949), Young and Falk (1956), Young and Christensen (1962), Fisher (1965; 1967), Hollingworth and Poffenberger (1917), and Engel (1928). Using a two bottle procedure, Pfaffmann and Young each found that, upon comparing percent licks for pairs of salt solutions, rats demonstrated a greater percentage of licks at salt solutions that contained concentrations between 0.3% and 1.5% than with other salt concentrations above or below this range. Fisher (1965; 1967) confirmed these findings using a similar procedure.

Using a brief-exposure preference procedure, Young and Christensen (1962) found that, given an opportunity to lick at cups which contained low concentrations of sucrose (0.5%, 1%, or 2%), rats showed a higher percentage of licks at those cups which contained a solution of one of these concentrations of sucrose plus a 0.75% salt concentration. At higher sucrose concentrations (4% or 8%), these investigators noted no significant preference for solutions which contained these concentrations only as opposed to solutions which contained both sucrose and (up to) 1% salt. They did find that, at higher concentrations of salt (2% and 4%), rats preferred to lick at solutions which contained only sucrose, as opposed to solutions which contained both sucrose and salt concentrations. This effect was confirmed by Christensen (1962) using "standard" solutions which contained one of several concentrations of sucrose (1%, 2%, 4%, 8%, 16%). When the "comparison" solution contained a higher concentration of sucrose than the standard, larger concentrations of salt in the salt-sucrose comparison solutions were required to shift the rats' preference to the standard away from the comparison.

If preference is associated with lower reaction time, the results of the present study confirm the findings obtained by Young and Christensen. The consequence of increased salt concentrations is an increase in GM median RT and GM SIQR at all sucrose parameters.

Another method by which to evaluate the effect of salt concentration on RT is to compare the median RT and SIQR for 0% salt with the median RT and SIQR for the highest tolerable salt concentration, at each sucrose parameter. Table 4 shows that substantial increases in GM median RT and GM SIQR result when salt is increased from 0% to the highest tolerable concentration, especially at the higher sucrose parameters.

The results for the group data reflect the results obtained for individual subjects (see Tables 5-11). Except for C5, the median RT for all subjects was longer at the highest tolerable salt concentration than at 0% salt, at each sucrose parameter. As for variability, four of the seven subjects exhibit an increase in median semi-interquartile range when these measures are compared at 0% salt with those obtained at the highest tolerable salt value, at each of the sucrose parameters.

Table 4: Group mean median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter.

% Salt	0	2.5	4	5	6
% Sucrose					
5	251(57)	269(79)	---	---	---
10	254(58)	---	290(80)	---	---
15	260(50)	---	---	300(76)	---
20	244(53)	---	---	---	302(70)
25	246(52)	---	---	293(72)	---

Table 5: Median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter, for subject C1.

% Salt	0	2.5	4	5	6
% Sucrose					
5	188(29)	198(39)	---	---	---
10	190(37)	---	202(36)	---	---
15	192(31)	---	---	214(45)	---
20	170(25)	---	---	---	207(30)
25	195(38)	---	---	207(34)	---

Table 6: Median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter, for subject C2.

% Salt	0	2.5	4	5	6
% Sucrose					
5	170(27)	198(105)	---	---	---
10	173(30)	---	216(102)	---	---
15	167(22)	---	---	205(65)	---
20	151(20)	---	---	---	221(88)
25	189(40)	---	---	252(109)	---

Table 7: Median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter, for subject C4.

% Salt	0	2.5	4	5	5.5
% Sucrose					
5	181(50)	188(55)	---	---	---
10	180(65)	---	184(51)	---	---
15	179(56)	---	---	194(62)	---
20	178(51)	---	---	---	201(58)
25	186(40)	---	---	217(53)	---

Table 8: Median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter, for subject C5.

% Salt	0	1	3	5	5.5
% Sucrose					
5	319(60)	303(64)	---	---	---
10	305(46)	---	335(60)	---	---
15	291(44)	---	312(48)	---	---
20	286(65)	---	---	---	334(60)
25	304(55)	---	---	311(61)	---

Table 9: Median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter, for subject C6.

% Salt	0	2.5	4	5	5.5
% Sucrose					
5	288(120)	338(125)	---	---	---
10	329(109)	---	356(140)	---	---
15	327(99)	---	---	389(134)	---
20	321(120)	---	---	---	364(127)
25	287(93)	---	---	316(106)	---

Table 10: Median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter, for subject C8.

% Salt	0	2.5	4	5	6
% Sucrose					
5	393(75)	433(78)	---	---	---
10	364(67)	---	492(69)	---	---
15	445(52)	---	---	500(74)	---
20	387(36)	---	---	---	483(53)
25	381(59)	---	---	453(71)	---

TABLE 11: Median RT in msec and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter, for subject C9.

% Salt	0	2	3
% Sucrose			
5	216(40)	239(71)	---
10	236(55)	---	245(63)
15	219(43)	---	235(52)
20	216(54)	---	273(86)
25	177(36)	---	208(52)

These findings indicate that RT variability (SIQR) is directly related to salt concentration.

The effects of salt concentration on response rate and variability are summarized in Table 12. At each sucrose parameter, the group mean response rate is lower at the highest tolerated salt concentration. The rate was greater at the lowest salt concentration (0%).

The effect on the variability in the rate of responding for increasing concentrations of salt is not consistent across sucrose parameters. At 5% and 15% sucrose, the SIQR is fairly constant; whereas at 10%, 20%, and 25% sucrose, the SIQR is much smaller at higher salt concentrations.

Figure 3 shows that increased concentrations of sucrose result in a non-monotonic RT function at 0% salt. The effect of increasing salt concentration is to raise the non-monotonic RT function across sucrose values.

When rate is the observed measure, an increase in sucrose concentration results in a non-monotonic function at 0% salt. The effect of increasing salt concentration is to lower the non-monotonic rate function across sucrose values (lower panel).

Indifference functions as a measure of preference

In studies relating concentration to palatability, Young (1949) and his associates (Young and Chaplin,

Table 12: Group mean median response rate in r/min and SIQR () for several parameters of sucrose: at 0% Salt; and at the highest concentration of salt for each sucrose parameter.

% Salt	0	2.5	4	5	6
% Sucrose					
5	3.27 (0.54)	2.20 (0.59)	---	---	---
10	3.93 (0.68)	---	2.13 (0.41)	---	---
15	2.92 (0.59)	---	---	1.55 (0.59)	---
20	3.89 (0.73)	---	---	---	1.14 (0.36)
25	4.43 (0.91)	---	---	2.20 (0.32)	---

1949; Young and Falk, 1956; Young and Christensen, 1962; Christensen, 1962) investigated the effects of sucrose and salt concentrations on behavior in order to obtain optimal preferential solutions, preferential thresholds, and points of indifference. Young, et al found that the optimal preferred concentration for sucrose was 11% with non-deprived rats; the optimal concentration for salt was between 0.75% and 1.5% (Young, 1949; Young and Falk, 1956). When non-deprived rats were given a choice between 4% sucrose solution and a 0.5% salt solution Young (1949) observed a slight preference for the 4% solution.

In a later report, Young (1960) asserted that isohedonic contours could be determined in the sweet-sour region of taste sensation. Isohedonic contours map pairs of taste stimuli "that are equal in hedonic intensity at different levels of intensity" (p.478).

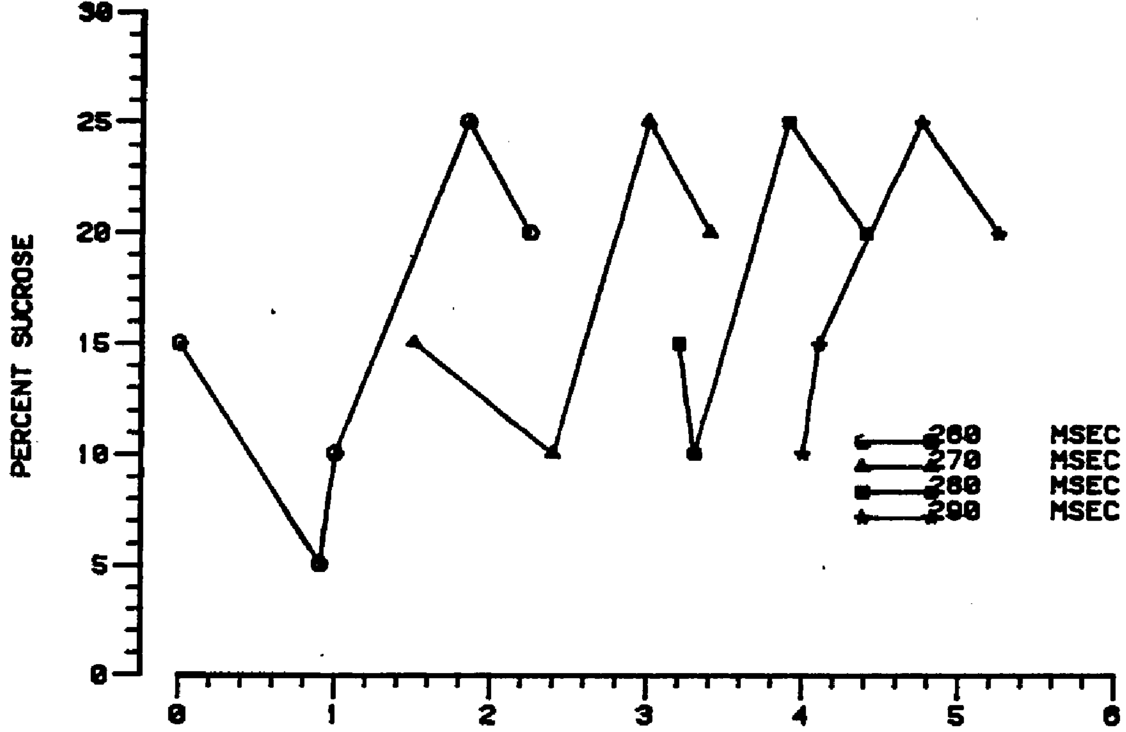
Empirical determinations of isohedonic intensity were investigated by Young and Christensen (1962) and Christensen (1962). Using the up-and-down procedure (Dixon & Massey, 1957), Christensen employed one of several values of sucrose concentration (1%, 2%, 4%, 8%, or 16%) with one of several values of salt concentration (0.5%, 1%, 2%, 4% or 8%). At low concentrations of salt (0.5 or 1.0%), lower concentrations of sucrose were needed to obtain "equal palatability" (the indifference point between a given sucrose-only concentration and some admixture of sucrose and salt, as measured by percent of licks). At higher concentrations of salt (2%, 4%, or 8%), however, larger concentrations of sucrose were required to maintain equal palatability. The family of indifference functions thus appear U-shaped, i.e. non-monotonic increasing. His study substantiated earlier findings (Young and Christensen, 1962).

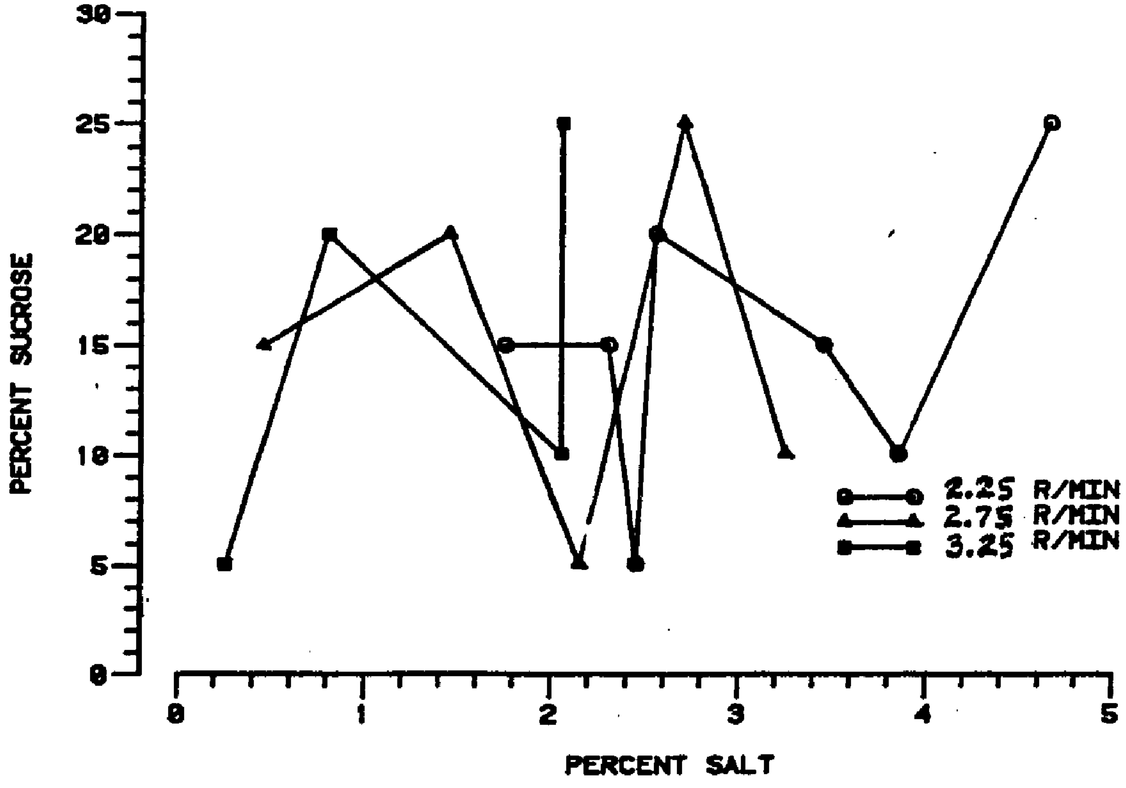
To compare the results from the present study with those obtained by Christensen, indifference functions were determined from ordered pairs of sucrose-salt concentrations at equal RT or equal response rate values taken from Figure 2. In Figure 22, median RT is the parameter in the upper panel; median rate is the parameter in the lower. The median RT parameters chosen were: 260; 270; 280; and 290 msec. The median rate parameters chosen were: 3.25; 2.75; and 2.25 r/min. From the S-shaped family of RT functions it can be seen that a decrease in sucrose concentration (from 15% to 5%) can accommodate a small increase in salt concentration (0% to 0.9%) and maintain a median RT of 260 msec. At higher concentrations of salt (from 0.9 to 1.85%), increased concentrations of sucrose (from 5 to 25%) are needed to remain on the 260 msec parameter. These results are consonant with the findings obtained by Christensen (1962). When salt is increased to

Figure 22. Indifference functions for group data.

This figure presents ordered pairs of sucrose-salt concentrations at equal RTs (upper panel) and equal response rates (lower panel). The data were taken from figure 2.

Subject: GR


PERCENT SUCROSE
0
5
10
15
20
25
30
0
1
2
3
4
5
6
260 MSEC
270 MSEC
280 MSEC
290 MSEC


PERCENT SUCROSE
0
5
10
15
20
25
30
0
1
2
3
4
5
PERCENT SALT
2.25 R/MIN
2.75 R/MIN
3.25 R/MIN

2.25%, however, less sucrose (20%) is needed to remain at the same RT parameter. This result would tend to confirm Guttman's (1953) finding, i.e. 16% sucrose (nearly 20% in this study) represents the most preferred sucrose concentration.

The shape of the family of indifference functions is determined by the effects of sucrose and salt. If sucrose were the major factor affecting RT, the family of functions would be ordered upward along the sucrose axis. On the other hand, if salt were the major factor, the functions would be ordered to the right, along the salt axis. If both sucrose and salt contributed equally, the family of functions would be ordered at a 45 degree angle to the origin. From the figure, it is clear that the effect of salt concentration is prepotent.

Although not quite so distinct as the family in the upper panel, upon close examination it can be seen that the family of functions in the lower panel is also ordered along the salt axis. this would indicate that salt is the prepotent factor affecting rate as well.

Correlation of RT with response rate

This study provided an opportunity to correlate latency with rate of responding. Earlier studies with dogs (Kellogg & Walker, 1938), and humans (Campbell & Hilgard, 1936; Campbell, 1938) revealed weak inverse correlations between latency and frequency measures. Based on the results of his study, Stebbins (1962) suggested that there may be an inverse relationship between latency to bar release and rate of responding.

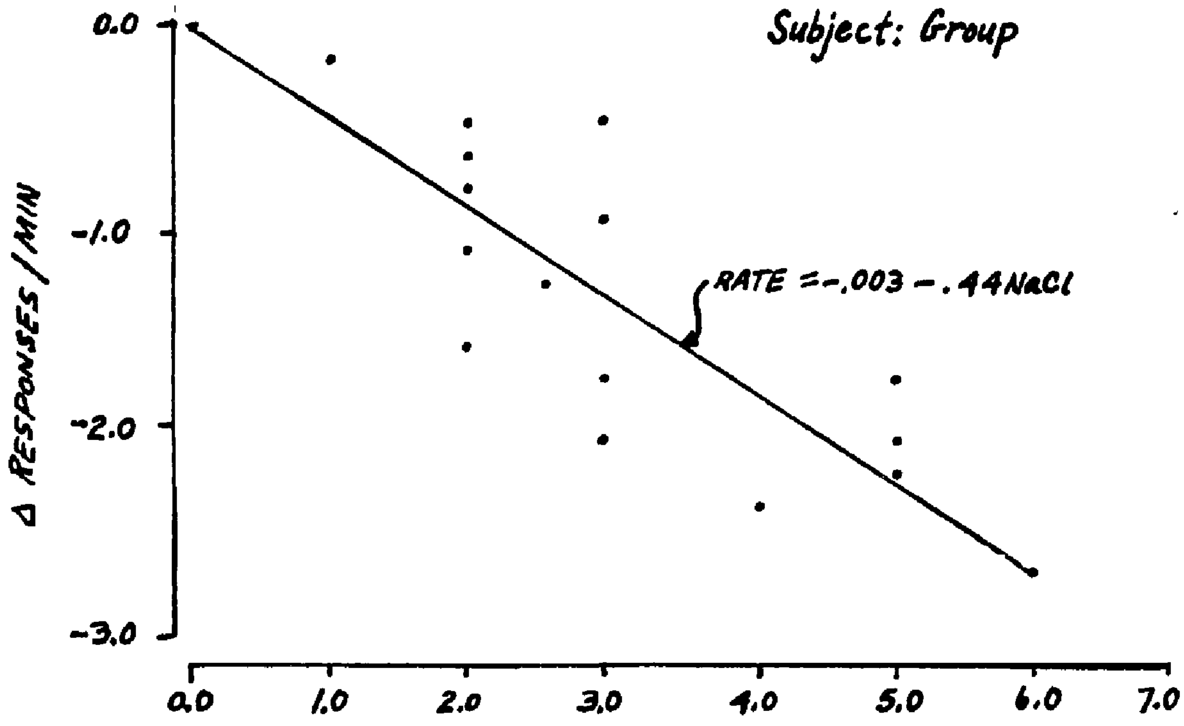
In an attempt to establish the existence of this relation, and to bring into perspective the change on the dependent measure which results from changes in the independent measure, the data were transformed in the following manner: for each subject, median RT and median response rate were initialized at 0% salt concentration, at each sucrose parameter. That is, the median response measure (RT or rate) at 0% salt, k% sucrose, was subtracted from the median response measure for each of the several salt-sucrose concentrations at k% sucrose. Mathematically, the transformation was obtained as follows:

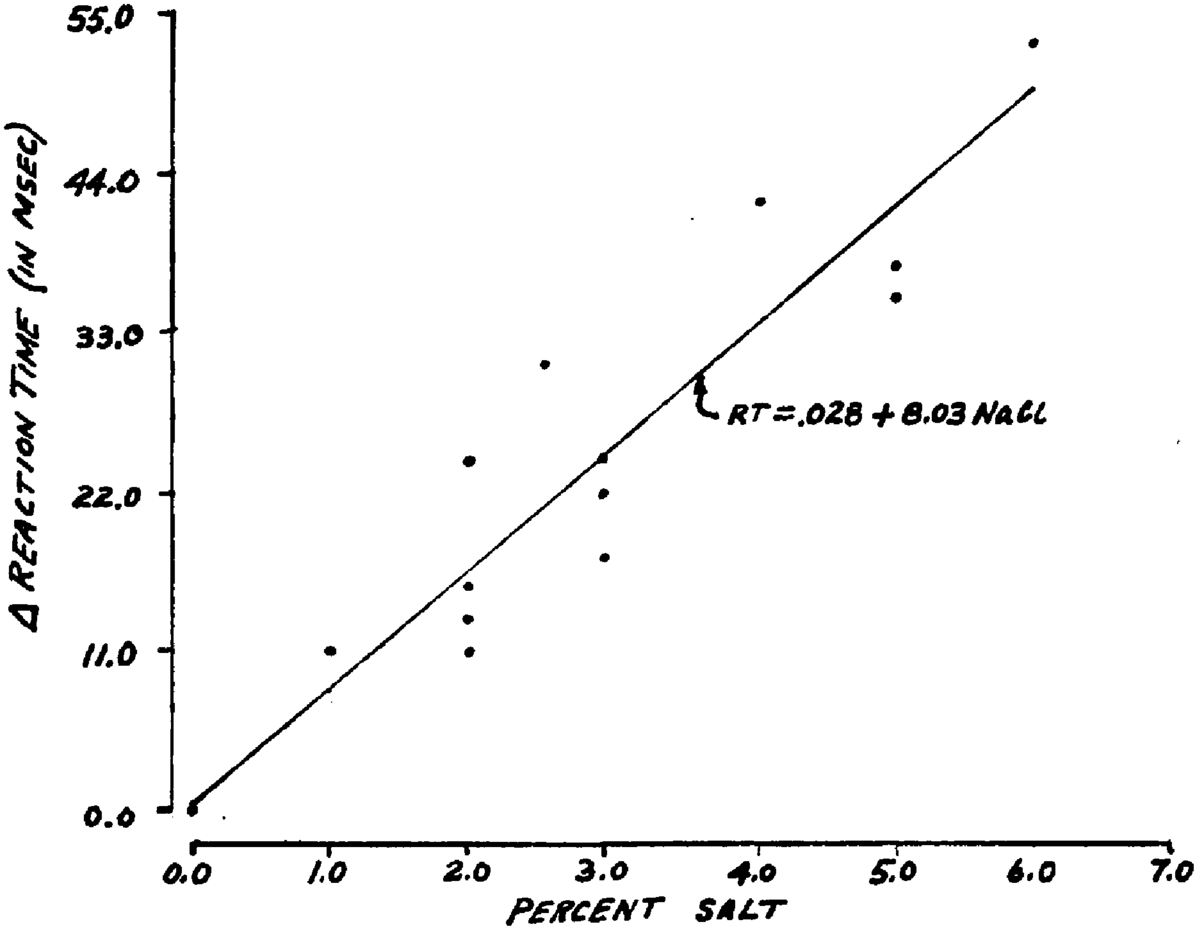
Median RT(j,k)* = median RT(j,k) - median RT(0,k)
Where j = percent salt concentration
And k = percent sucrose concentration

Thus, for example, for subject C1 (whose median RT and median rate at 0% salt 25% sucrose were 195 msec and 7.02 r/min, respectively), his median RT and median response rate at 0% salt 25% sucrose were set to 0 msec and 0.0 r/min, respectively. Then, 195 msec was subtracted from 207 msec (and 7.02 r/min was subtracted

Figure 23. Transformed group RTs and group response rates as a function of salt concentration.

This figure shows group RTs (upper panel) and group response rates (lower panel) initialized at 0% salt, at each sucrose parameter. Salt is the independent measure. The trend line depicted is the linear regression equation obtained for the transformed data.


Subject: Group
Δ RESPONSES / MIN
0.0
-1.0
-2.0
-3.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
RATE = -.003 - .44NaCl


Δ REACTION TIME (IN MSEC)
55.0
44.0
33.0
22.0
11.0
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
PERCENT SALT
RT = .028 + 8.03 NaCl

from 4.89 r/min) to obtain the transformed median RT (and transformed median response rate) for C1 at 2% salt 25% sucrose. The transformed median RT (and median response rate) were then averaged for all seven subjects at each salt-sucrose combination. The data from these results are plotted in Figure 23.

As noted earlier, the functions obtained indicate that as salt concentration is increased, median RT increases, at all sucrose parameters (see Figure 23, upper panel). Also, as salt concentration is increased, median rate generally decreases, at all sucrose parameters (lower panel). The linear transformation used to indicate the relative effect of salt on each of the dependent variables is equivalent to one in which a linear regression is determined (Cf. Hays, 1973, p.621 ff.). The obtained regression equation for response rate on salt was:

$R^* = -.003 - .44n$,

Where R^* = transformed rate

And n = percent salt concentration

The ordinate intercept is necessarily near zero. The Pearson product-moment coefficient, r equals $-.90$ which is significant at the .00001 level. The coefficient of determination is .81. Where the dependent measure was RT, the regression equation for the relationship between salt and RT was:

$RT^* = .028 + 8.03n,$

Where RT^* = transformed RT

and n = percent salt concentration.

The Pearson product-moment coefficient, r equals .96 which is significant at the .00001 level. The coefficient of determination is .91.

Finally, to establish the relationship between the two response measures, a linear regession equation was obtained for RT and response rate. The data, along with the regression line, are shown in Figure 24. The equation obtained was:

$R^* = -.042 - .05RT^*.$

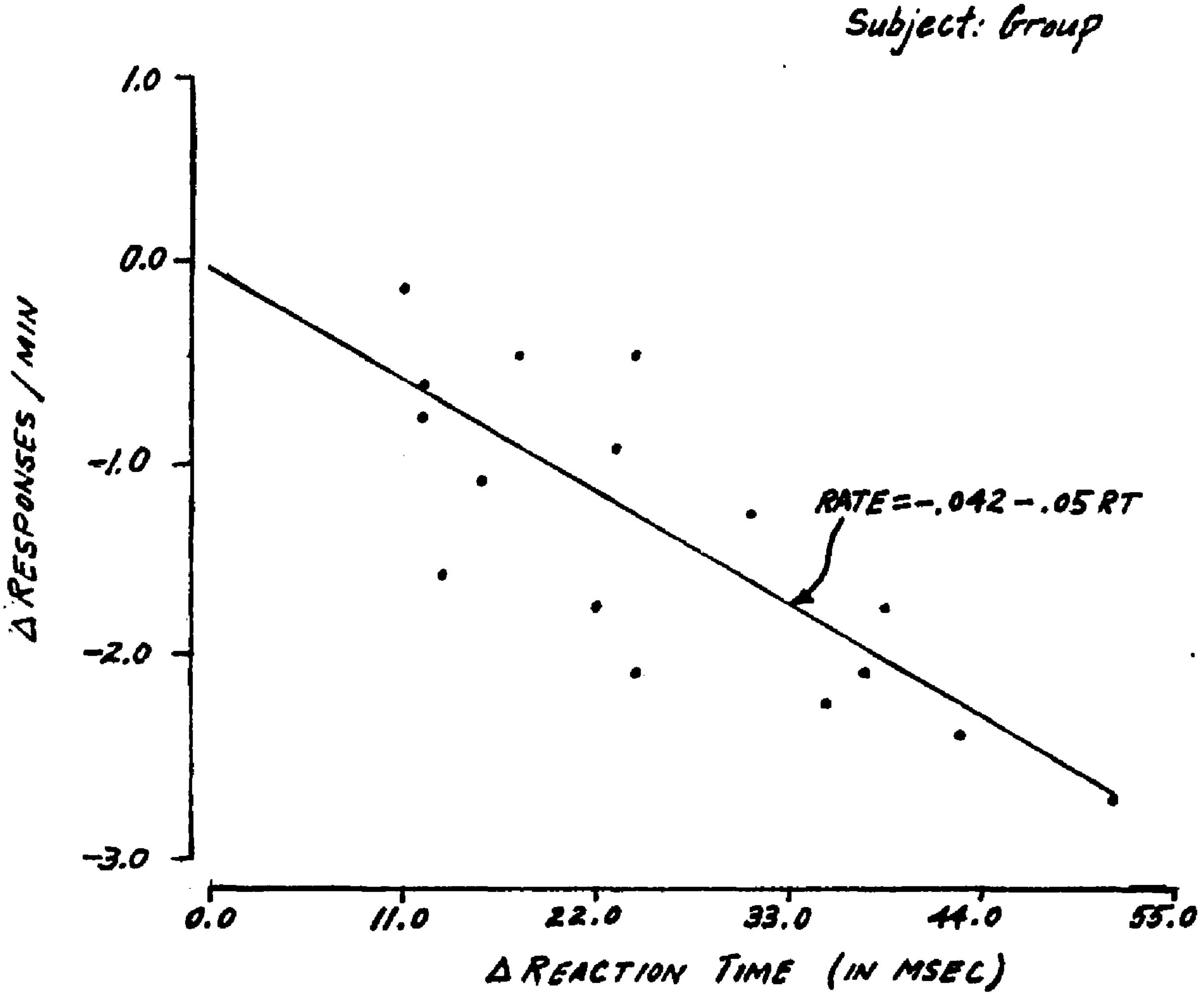
The Pearson product-moment coefficient, r equals -.89 at a .00001 significance level. The coefficient of determination is .80. Thus it appears that, in this study, response rate and RT are inversely related, as Stebbins suggested.

Summary and conclusions

It is evident from the data obtained in the present study that both sucrose and salt effect changes in the primary measure, RT, and in the secondary measure,

Figure 24. <u>Correlation of tranformed group RT with transformed rate</u>.

This figure depicts the relation between the transformed measures of RT and response rate. The trend line is the linear regression equation obtained for these data.


Subject: Group
1.0
0.0
-1.0
-2.0
-3.0
Δ RESPONSES / MIN
RATE=-.042-.05 RT
0.0
11.0
22.0
33.0
44.0
55.0
Δ REACTION TIME (IN MSEC)

response rate. It is also clear from the data that, gram for gram, salt has a more profound effect on either response measure than does sugar.

These conclusions can be further illustrated: for the group, the shortest median RT occurs at the 20% sucrose parameter, where the salt concentration is 0%, at that salt parameter, the longest median RT occurs at the lowest sucrose concentration (2%). In Table 3, the median RT for five subjects are shown for these sucrose parameters. The average increase in median RT is 36 msec, with an average increase in SIQR of 10 msec. On the other hand, when the median RT for these subjects are compared at the 20% sucrose parameter with 0% salt as opposed to the highest concentration of salt, the average increase in their RT is 57 msec, with an average increase in SIQR of 26 msec. These data are found in Table 13.

It could be argued that the differences in RT were due to the differences in the highest tolerable salt concentrations at the several sucrose parameters. There were, however, three subjects (C1, C2, and C8) which were exposed to both 20% and 2% sucrose at the 0% salt parameter, and to both 0% and 6% salt at the 20% sucrose parameter. These data are presented in Table 14. The average increase in median RT for these subjects at the differing concentrations of sucrose was 47 msec, with an average increase in SIQR of 15

Table 14: Median RT in msec and SIQR () for three subjects at two sucrose concentrations at 0% Salt; and two salt concentrations at 20% Sucrose.

% Sucrose	20	2	20	20
% Salt	0	0	0	6
subject				
C1	170(25)	223(37)	170(25)	207(30)
C2	151(20)	173(31)	151(20)	221(58)
C8	387(36)	453(59)	387(36)	486(53)
GM				
increase		47(15)		68(30)

Table 13: Median RT in msec and SIQR for individual subjects for 0% Salt and the highest concentration of salt at the 20% Sucrose parameter.

percent salt	0	5.5	6
subject			
C1	170(25)	---	207(30)
C2	151(20)	---	221(88)
C4	178(51)	201(58)	---
C8	387(36)	---	483(53)
C9	216(54)	273(86)	---

msec; whereas, the average increase in RT at the differing concentrations of salt was 68 msec, with an average increase in SIQR of 30 msec. The conclusion that the effect of salt on RT is relatively greater than the effect of sucrose is supported.

As for the rate measure shown in Table 15, the average decrease in response rate at differing concentrations of sucrose was smaller than the average decrease in rate at differing concentrations of salt. These data are compatible with the results obtained for the whole group and for individual subjects. Thus, the conclusion that the effect of salt on response rate is greater than the effect of sucrose is also supported.

These findings are also supported by the results obtained by Christensen (1962). In particular, he found that at high concentrations of salt, greater concentrations of sucrose were required to maintain equal palatability. In the present study, at higher concentrations of salt, greater concentrations of sucrose were required to maintain equal RT's (cf. Figure 22).

As stated elsewhere, another purpose to this study was to determine whether these response measures were interrelated. Given the results presented in Figure 24, that the correlation coefficient is -.89 and that the coefficient of determination is .81, one must conclude that the relationship between rate and RT is both

Table 15: Median rate in r/min for several subjects at two sucrose concentrations at 0% Salt; and at two salt concentrations at 20% Sucrose.

% Sucrose	20	2	20	20
% Salt	0	0	0	6
subjects				
C1	6.65	1.58	6.65	1.54
C2	4.67	1.45	4.67	0.28
C8	4.27	0.87	4.27	0.53
GM				
decrease		3.90		4.41

strong and significant. As Stebbins' conjectured (1962), the relationship is an inverse one. Moreover, these data would lend support to Hull's (1943) assertion that reaction potential and latencycy of response are inversely related. Finally, these data suggest that either response rate or RT is an efficacious measure of the strength of reinforcement.

To the extent to which indifference functions could be determined, Figure 22 presents a family of indifference curves for the group data at four arbitrarily chosen RT parameters and three rate parameters. These functions are notable as follows: in the first instance, they are clearly not monotone decreasing. This would indicate that preferences for sucrose or salt (or both) are also non-monotonic. This conclusion is supported by earlier findings, notably Guttman (1953), Young (1949), and Young and Christensen (1962). If the indifference functions are not monotone decreasing, manipulations of other parameters of the reinforcer, e.g. volume, might present unusual results insofar as the theory of consumer demand is concerned.

Specifically, the monotone decreasing functions of demand theory predict that in the two-commodity model: if the consumer increases his consumption of commodity X, he must concommitantly decrease his consumption of commodity Y to remain on the same indifference function.

In addition, when he is consuming large amounts of X at any indifference function, he must relinquish greater amounts of Y to gain one more unit of X than if he were consuming at much lower amounts of X. These conclusions are forced by the shape of the (monotone decreasing) family of indifference functions.

The data obtained in the present study suggest that the predictions made according to this model are incomplete. In particular, the lower legs of the S-shaped indifference functions located in the upper panel of Figure 22 conform to the shape of the monotone decreasing functions in Figure 1. That is, at low concentrations of sucrose (from 15% to 5%) the subjects relinquish some amounts of sucrose concentration to obtain increased amounts of salt (from 0% to 0.9%). However, to remain on the same indifference function (e.g. 260 msec), the subjects require greater quantities of sucrose (from 5% to 25%) to consume greater concentrations of salt (from 0.9% to 1.8%). These results, supported by the findings obtained by Young and Christensen (1962), would suggest that the indifference functions of demand theory are more complex than were originally proposed. Moreover, the disutility of larger amounts of some commodities must be accounted for to present the model more precisely.

Secondly, it should be noted that the rate functions (lower panel) intersect one another. If equal rates contain all pairs of sucrose-salt combinations for which the subject is indifferent, then all ordered pairs on one "iso-rate" function will be preferred to any such pair on some other iso-rate function. Thus it would be the case that all ordered pairs contained on the 3.25 r/min function would be preferred to any pair from the 2.75 r/min function, if higher rates are indicative of preference. If one pair of sucrose-salt values is contained in both sets, the assumption of transitivity is violated.

Table A1: RT SIQRs for each subject at 25% sucrose and several parameters of salt.

Percent salt	0	2	3	5
Subject				
C1	38	34	31	34
C2	40	44	60	109
C4	40	37	43	53
C5	55	51	51	61
C6	91	110	96	106
C8	59	60	63	71
C9	36	35	52	--

Table A2: RT SIQRs for each subject at 20% sucrose and several parameters of salt.

Percent salt	0	2	3	5	6
Subject					
C1	25	24	26	29	30
C2	20	21	29	100	88
C4	51	47	43	50	58
C5	65	48	62	67	60
C6	120	107	114	119	127
C8	36	56	48	56	59
C9	54	50	86	--	--

Table A3: RT SIQRs for each subject at 15% sucrose and several parameters of salt.

Percent salt	0	2	3	5
Subject				
C1	31	33	33	45
C2	22	28	28	65
C4	56	42	51	62
C5	44	50	48	62
C6	99	119	113	134
C8	52	63	68	74
C9	43	50	52	--

Table A4: RT SIQRs for each subject at 10% sucrose and several parameters of salt.

Percent salt	0	2	3	4
Subject				
C1	37	27	28	36
C2	30	40	55	102
C4	65	59	64	51
C5	46	89	60	--
C6	109	99	102	140
C8	67	67	71	69
C9	55	60	63	--

Table A5: RT SIQRs for each subject at 5% sucrose and several parameters of salt.

Percent salt	0	1	2	2.5
Subject				
C1	29	32	35	39
C2	27	24	45	105
C4	50	81	9b	55
C5	60	64	--	--
C6	120	123	139	125
C8	75	72	61	78
C9	40	62	51	71

Table A6: Rate SIQRs for each subject at 25% sucrose and several parameters of salt.

Percent salt	0	2	3	5
Subject				
C1	.71	.49	.83	.80
C2	1.27	.33	.35	.22
C4	1.23	.91	.56	.26
C5	.92	.71	.20	.24
C6	.26	.90	.33	.21
C8	.45	.45	.20	.18
C9	1.56	.03	.80	---

Table A7: Rate SIQRs for each subject at 20% sucrose and several parameters of salt.

Percent salt	0	2	3	5	6
Subject					
C1	1.23	.79	.58	.76	.93
C2	.88	.55	.53	.16	.12
C4	.46	.63	.36	.29	.12
C5	.78	.47	.26	.30	.74
C6	.21	.28	.10	.08	.18
C8	.18	.22	.39	.15	.05
C9	1.36	.65	.37	---	---

Table A8: Rate SIQRs for each subject at 15% sucrose and several parameters of salt.

Percent salt	0	2	3	5
Subject				
C1	.98	.63	.62	.48
C2	.63	.48	.32	.17
C4	.69	.86	.75	1.28
C5	.49	.28	.29	---
C6	.31	.18	.46	.79
C8	.48	.15	.11	.22
C9	.52	.38	1.38	---

Table A9: Rate SIQRs for each subject at 10% sucrose and several parameters of salt.

Percent salt	0	2	3	4
Subject				
C1	.56	.47	1.29	1.02
C2	.58	.23	1.80	.12
C4	.94	.59	.46	.18
C5	.55	.44	.17	---
C6	1.60	.39	.31	.62
C8	.23	.46	.15	.12
C9	.30	.28	.31	---

Table A10: Rate SIQRs for each subject at 5% sucrose and several parameters of salt.

Percent salt	0	1	2	2.5
Subject				
C1	.64	.29	1.02	.82
C2	.61	.49	1.31	.29
C4	.45	1.24	.37	.99
C5	.27	.38	---	---
C6	1.10	1.01	.29	.79
C8	.35	.09	.05	.07
C9	.34	.78	.26	.55

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