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Associative processes and strategies in disjunctive reaction time

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Scaling analysis based on variable criterion theory has been applied to the c-reaction form of disjunctive RT. In addition to previously identified sensory growth functions, two associative processes have been identified and functions of time describing their growth have been obtained. Associative strength to the positive stimulus begins at about 200 msec, or after, and grows with initial positive and later negative acceleration. Associative inhibition to the negative stimulus begins earlier, shortly after the sensory detection functions, and grows rapidly with negative acceleration. Subjects may adopt strategies which emphasize the use of either of these associative processes. With the pure inhibitory strategy, they respond to the positive stimulus entirely on the basis of sensory detection, but associatively inhibit response to the negative stimulus. With either strategy, the speed-accuracy tradeoff was determined by the level of criterion adjustment.

To describe the temporal growth in the strength of the sensory and associative information leading to response evocation is one of the goals of variable criterion theory. This type of analytic approach is made possible by the scaling properties of the model based upon the normality of criterion distributions. The logic involved and the methods by which such functions may be derived from cumulative RT distributions have been described by Grice (1972b) and Grice, Hunt, Kushner, and Morrow (1974). Considerable progress has been made in the description of the growth of the sensory component. These functions are obtained from simple RT experiments in which the associative factor may be assumed to be absent. The basic model here is $E = V - T$, where V is sensory strength, T is the mean of the criterion distribution, and E is excitatory strength measured from T. V grows in strength following stimulus onset according to a negatively accelerated function. The rate of growth is a function of stimulus intensity. The probability of response at any time is given by $\Phi(E,\sigma)$, where Φ is the normal function and σ is the standard deviation of the criterion distribution. The study by Grice et al. (1974) included three simple RT conditions with differing catch trial conditions designed to affect the criterion level. The auditory signal was also presented at three intensities in an irregular order. For each subject a family of three negatively accelerated functions was derived indicating the growth of V with respect to time for each intensity. Estimates of T and σ were also obtained which described the relations between conditions and between experimental sessions. This family of three functions, together with the criterion parameters, provided quite a satisfactory description of the data.

The situation with respect to discovery of the growth functions for associative information in RT research is less advanced. The model which has been successfully applied in eyelid conditioning (Grice, 1972a) is $E = H + V - T$, where H is the associative factor; and it is the intent to apply this model to disjunctive RT. In the research by Grice et al. (1974), there were also three disjunctive RT conditions (c reaction) in which the catch signals were also auditory signals. The intensities of both the RT and catch signals were manipulated in the same way as in the simple RT conditions, and one of the three conditions was a speed-accuracy tradeoff condition. While it appeared that the growth functions were not the same as in simple RT, attempts to apply the scaling model to the disjunctive conditions were not successful. This was because of considerable inconsistency in performance, interpreted as changes in strategy, which appeared related to the complexity of the task facing the subject. However, considerable evidence concerning the relative rates of growth of sensory and associative information was obtained from a two-dimensional analysis of information transmitted which was applied to successive stages of the cumulative distributions. The conclusion drawn from this analysis was that sensory strength (detection) grows at a considerably faster initial rate than does associative strength. Thus, on low-criterion trials the subject is forced to respond on the basis of detection only, and in the absence of associative information. As time passes the dependence of response upon stimulus intensity essentially disappears and association progressively takes over.

The primary purpose of the research reported here was to obtain data similar to that of the Grice et al. (1974) research, but of sufficiently greater stability that the temporal growth of association could be investi-

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gated with the scaling procedure. The major change was to decrease the number of signal intensities from three to two. In addition to decreasing the complexity of the task, this also made it possible to increase the number of trials to which each stimulus was presented in each experimental session. In the condition designed to produce the speed-accuracy tradeoff, a deadline procedure was used rather than the previous speed instructions.

Considerable success was attained in obtaining greater stability of performance. Substantial portions of the data collected could be analyzed by the scaling procedures, and convincing functions have been obtained indicating the growth of associative processes. One unforeseen, but important, finding was that there are not one, but two associative processes with different temporal properties. One of these enables the subject to inhibit associatlvely response to the negative stimulus. The other is interpreted as positive associative strength to the positive stimulus. Furthermore, these two processes provide the basis for two alternative strategies which may be used separately or in combination in the performance of this task. One of these may be termed the inhibitory strategy and the other the positive, associative strategy.

METHOD

Subjects

The subjects were five young male adults who were paid for participation. All were psychology graduate students. Subjects 1, 2, and 3 had previously served in the experiment by Grice et al. (1974) and had the same designations in that report.

Procedure and Apparatus

The apparatus and general procedures have been previously described (Grice et al., 1974). A light warning signal of .5-sec duration preceded all signals by .5, 1.5, or 2 sec. Errors (false alarms) in the disjunctive conditions were signaled by the illumination of a red window bearing the word ERROR. In the deadline condition, responses of latency greater than the deadline were signaled by the illumination of a yellow window bearing the word SLOW. The RT signal was always a 1,000-Hz tone of either 50 or 100 dB SPL. In disjunctive conditions the catch signal was an 1,800-Hz tone of the same intensities. The experimental conditions were as follows:

Simple, 1/10: 100 trials of each intensity of the 1,000-Hz tone and 20 blank catch trials in an irregular order.

Simple, 1/3: the same but with 100 catch trials.

Disjunctive/accuracy: 100 trials of each intensity of the RT signal and 50 trials of each intensity of the catch signal–all in an irregular order. Subjects were instructed to respond quickly, but to avoid errors.

Disjunctive/deadline: the same, but with the deadline signal added. Subjects were instructed to beat the deadline as often as possible. The deadline was designed to produce substantial speeding and was determined for each subject separately. It was the general median RT to the 100-dB tone in the five preceding sessions in the accuracy condition. It was presented on 100-dB trials only.

The experiment began with one familiarization session in the simple 1/3 condition. There followed five sessions each of conditions simple 1/10 and 1/3, and disjunctive/accuracy. These sessions were conducted in a different irregular order for each subject. Finally, there were five sessions of the disjunctive/deadline condition. Each session began with 20 warm-up RT trails, 10 of each intensity. Also included in the warm-up were catch trials of the same type and proportion as the condition. In all, each subject participated in one practice and 20 experimental sessions.

RESULTS AND THEORETICAL ANALYSIS

The basic procedures for reducing the data to the terms of the model have been described in previous papers, e.g., Grice (1972b) and Grice et al. (1974). The data for each experimental session were first reduced to cumulative probability distributions, for each intensity separately, computed at 10-sec intervals. These distributions were then transformed to normal deviates. According to the model, the resulting functions indicate the growth of excitatory strength (E) on a scale in which zero is the mean of the criterion distribution and the unit is its standard deviation. The next step is to obtain more reliable estimates of these functions for each condition by combining as many experimental sessions as possible. Sessions may be combined appropriately only if there is satisfactory evidence that performance was on a consistent basis in all sessions to be combined. Evidence of consistency and the required scaling parameters T and σ are obtained from a between-sessions response evocation characteristic (REC) which has been described in the previous papers. Briefly, here, an REC consisted of a plot of the scale values for one session plotted against those of another at corresponding intervals of elapsed time. These plots were made at 10-msec intervals within the overlap of the two distributions. Under the assumption of normality of the criterion distributions, this plot will be linear, *provided* the subject is responding to the stimulus information in the same way in both sessions. The slope of a fitted line estimates the ratio of the σs of the two criterion distributions, and the two intercepts estimate the distance between their means in units of the two σs. Strictly speaking, there are two RECs for each pair of sessions, one for each intensity. However, both of these should estimate the same criterion parameters, i.e., have the same slope and intercept, and it should be possible to treat them as one. This is what was done, both here and by Grice et al. (1974). To obtain the necessary scaling parameters requires one less REC than the number of sessions or conditions being scaled, so there were four for each condition for each subject. Mutual regression lines were fitted to these by the weighted least squares method described by Grice et al. (1974, p. 770, Note 1.). Systematic departure from linearity may be produced in either of two ways. One is by lack of normality due to the failure to maintain a consistent criterion level. The other is a change between sessions of the strategy in reacting to the stimulus information. Systematic separation or divergence of the

RECs for the two intensities is most probably due to a change in strategy with respect to signals of one intensity only. Thus, the theoretical analyses were limited to those pairs of sessions for which the regression line provided a good fit to the combined REC based on the distributions of both intensities. These decisions were actually based upon visual inspection, but one aspect of them may be objectified. The fitting program used yielded the value of r^2. In this context the value of r^2 may be regarded as a close approximation to the proportion of the total variance in both sessions, including both intensities, which is accounted for by the single regression line.[1] Since this was a weighted solution, this is weighted variance. In no instance was the value of r^2 below .935 for any of the data included. Its mean value for the 40 RECs included in the final analyses was .962. There were, however, some instances excluded which were above .935 in which there was small but systematic divergence or separation of the intensities. In the case of the simple RT conditions, essentially all of the data could have been included. However, a complete analysis of simple RT was included in the previous paper, and the only purpose of including them here was to obtain estimates of the sensory growth functions for use in the analyses of the disjunctive conditions. Since the best possible estimates of these functions were desired, only sessions with the most consistent performances were used. It is important to note that limiting the following analyses to sessions with consistent performance places no constraints upon the outcomes of the analyses other than assuring that none of the obtained functions are artifacts of inconsistent performance.

The next step was to obtain the average functions for the growth of E, for those sessions included in each condition, for both the 100-dB (loud) and the 50-dB (soft) stimuli. In order to do this all sessions were converted to a common scale. Units were adjusted by means of the estimates of σ_x/σ_y, the slope. Adjustments to a common origin were made by means of the estimates of $T_x - T_y$, the intercept. The convention used here was that the earliest session used within the condition provided the common scale, i.e., the mean of its criterion distribution became the common origin and its σ became the unit. Following the rescaling, the means of the scale values were taken at each 10-msec interval.[2] The resulting functions were quite regular and provided the basis for the remaining analyses. Similar functions were also obtained from the error distributions in the disjunctive/deadline condition. Their scaling was based on the more reliable estimates of the session parameters from the RECs based on correct responses. While some errors did occur in the accuracy condition, they were not of sufficient number to permit analysis.

The functions obtained from simple RT which describe the growth of sensory strength (V_L and V_S) based on the two stimulus intensities were fitted with mathematical equations. As in the findings of Grice et al. (1974), these were negatively accelerated functions, the rate of growth depending upon stimulus intensity. In that study they were fitted with exponential growth functions. Here, however, some of the functions showed slight amounts of initial positive acceleration or nearly linear segments before negative acceleration. In order to obtain the best description possible of each subject's detection functions, these were fitted by the Gompertz growth function. Those showing negative acceleration throughout were fitted with the exponential growth function. Excellent fits were obtained in all cases. These functions will be presented only in connection with the subsequent analyses of disjunctive RT.

As mentioned above, these analyses have indicated the existence of two associative processes—one related to inhibition of response to the negative stimulus, and the other to associative response to the positive stimulus. In this experiment, three of the subjects appear to have adopted a strategy relying upon the inhibitory process, and two have based their performance upon positive association. We shall present the analyses of these two classes of subjects separately. In each case, we shall present the analysis of a single subject's data in some detail, but only the results of the analysis for the other subjects.

Evidence for Associative Inhibition

Analysis of performance in the disjunctive conditions began by determining the relationship to that of simple RT. This was done with the REC scaling procedure. The averaged scale values for the disjunctive conditions were plotted against the corresponding computed values from the functions fitted to the simple RT data. In other words, the loud scale values were plotted against computed values of the V_L function at 10-msec intervals and the soft scale values were plotted against the V_S function. Examples of such functions for Subject 2 are presented in Figure 1. Data for the accuracy condition, based on two experimental sessions, are presented in the lower panel. The result is that the relationships for loud and soft are essentially the same and, except for minor distortion in the upper tails, linear. The line is fitted to the loud and soft data in combination. In this case, it is a conventional least squares regression line, treating the calculated values from the fitted functions as error free. This linear relationship with the two growth functions from simple RT accounts for 97.8% of the variance of the accuracy scale values. The interpretation of this relation from the point of view of variable criterion theory is quite simple and straightforward. The implication is that the subject was responding to the same stimulus information in both conditions with only a criterion change. In units of the simple RT analysis, the criterion was raised by 1.273 scale units and the standard deviation was decreased

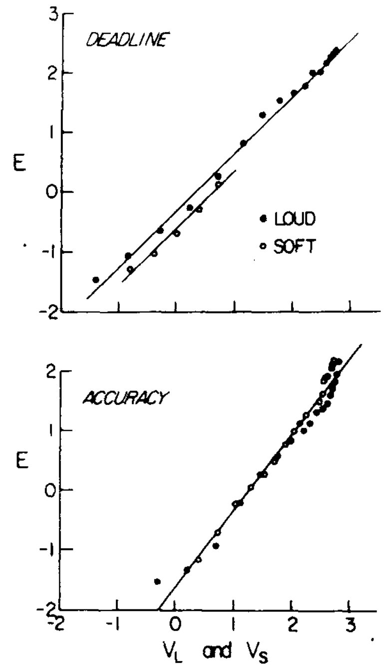

Figure 1. RECs for Subject 2 relating loud and soft scale values from the deadline and accuracy conditions to computed values from the sensory growth functions (V_L and V_S) derived from simple RT data. Points are at 10-msec intervals.

from unity to .782. Thus, we are led to conclude that the subject was responding purely on the basis of sensory strength or detection information. The model, then, is the same for simple and disjunctive RT: $E = V - T$. The only difference is in the values of the criterion parameters. The two calculated growth functions with the linear transformation representing the criterion shift are presented in the lower panel of Figure 4. The data points are the accuracy scale values. It should be noted that the two criterion parameters are the same for both functions and the only ones estimated from the accuracy data. While the fit is fairly good, it may be noted that it is the least adequate for the accuracy condition among the three subjects of this type.

If response is made to the positive stimulus purely on the basis of detection, and the subject is still able to avoid errors, it is an obvious inference that he must be able to inhibit associatively response to the negative stimulus. Evidence concerning the properties of the inhibitory process, however, must come from experimental conditions in which errors occur with sufficient frequency that the circumstance of its success and failure may be observed.

The RECs for Subject 2 relating the disjunctive/deadline condition to the simple RT V functions are presented in the upper panel of Figure 1. The data are based on four of the five experimental sessions in the condition. This picture is somewhat more complex than that for accuracy, but it is interpretable. The scale values for the loud stimulus are again a simple linear function of the computed values of V_L. This linear relation accounts for 99.4% of the variance in the loud scale values. The five data points for the soft stimuli plotted as a function of V_S are only the five fastest class intervals from 180 to 220 msec. The points beyond 220 msec, which are not included, gradually approach the line for the loud stimulus. The line fitted to the five points is parallel with the slope of the loud function, but displaced downward by .328 scale units. It accounts for 95.2% of the variance. The interpretation of this is clear enough, but largely because it occurred in more exaggerated form in other subjects. It is a special strategy induced by the experimental procedure of using a deadline signal for the loud intensity only. Thus, response to the soft stimulus was initially inhibited, in this subject, only slightly. After 220 msec he gradually relaxed this inhibition. We have called this delay inhibition (D_I) and, in order to obtain a complete descriptive model, have estimated its time course for the four of the five subjects who clearly showed it. The line parallel to the loud function indicates that it was constant until 220 msec. Its subsequent decrease was estimated from the gradual increase of the following points above the extrapolation of this line. These residuals are plotted in the function at the top of Figure 2. The fitted curve is an exponential growth function. The entire function for D_I consists of the initial constant level with this later function subtracted. While our use of the deadline signal for the loud signal only produced a complicating factor in the data, it is encouraging that the model was able to detect the resulting strategy and provide a quantitative description of it.

Functions describing the course of associative inhibition are estimated from the average functions indicating the growth of response strength to the negative stimulus based upon the error distributions. The amount of inhibition effective at any time is the distance of the

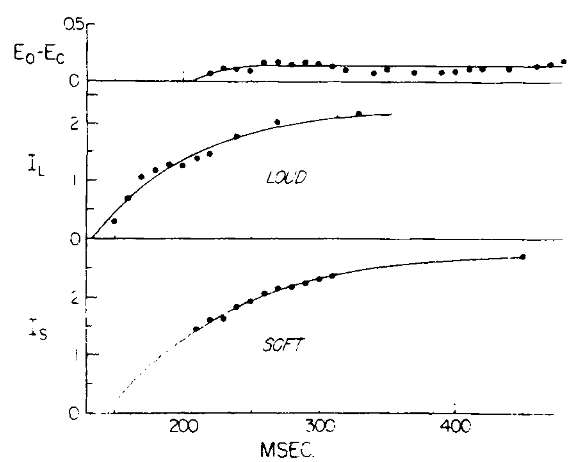

Figure 2. Data from Subject 2. The top figure gives the increase in E resulting from the decrease of delay inhibition to the soft tone. The lower two figures give the data points (E correct – E errors) and the fitted functions indicating associative inhibition.

error function below the strength of V at that time. The criterion parameters for the condition were estimated from the line fitted to the loud correct response data, since this is uncomplicated by the special delay strategy applied to soft. Using these parameters, the two V functions were then transformed to the scale of the deadline condition. In the case of the loud stimuli, the growth of associative inhibition was estimated simply by subtracting the error scale values from values computed from the transformed V_L function at 10-msec intervals. In the case of the soft stimuli, it was necessary first to subtract the delay inhibition function from V_S before subtracting the error scale values. The resulting points, estimating the growth of associative inhibition, are plotted in the lower portions of Figure 2. They resulted in orderly, negatively accelerated relations, which were fitted with exponential growth functions. It will be noted that amount of inhibition is somewhat larger for the soft stimulus. This was also true of the other subjects, but it may not represent a general principle with respect to stimulus intensity. The 10-sec rise time used in switching the tones reduced, but did not entirely eliminate the onset transient. The greater audibility of the transient at 100 dB would tend to make these tones less discriminable.

The entire model for the deadline condition may now be stated. For the positive stimuli it is $E_{L+} = V_L - T$ and $E_{S+} = V_S - D_I - T$. For the negative stimuli it is $E_{L-} = V_L - I_L - T$ and $E_{S-} = V_S - I_S - D_I - T$, where I_L and I_S represent associative inhibition. The computed component functions are presented graphically in Figure 3. The resulting combined functions representing the growth of E to each of the four stimuli

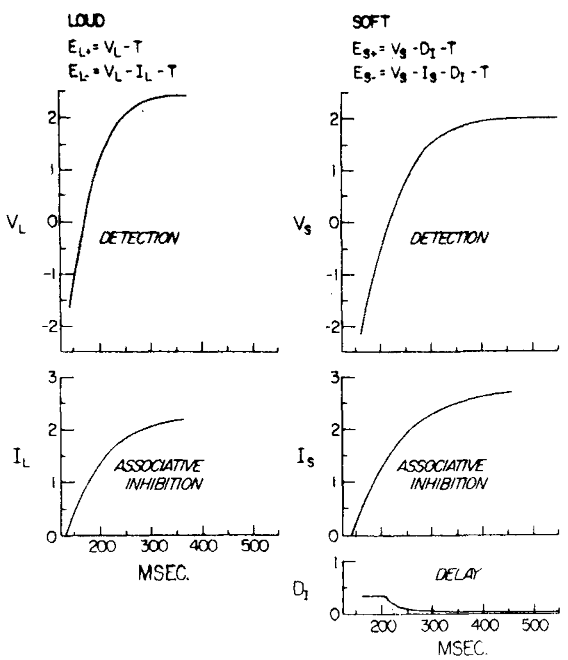

Figure 3. Graphs of the equations describing the component functions of the model for the performance of Subject 2 in the deadline condition.

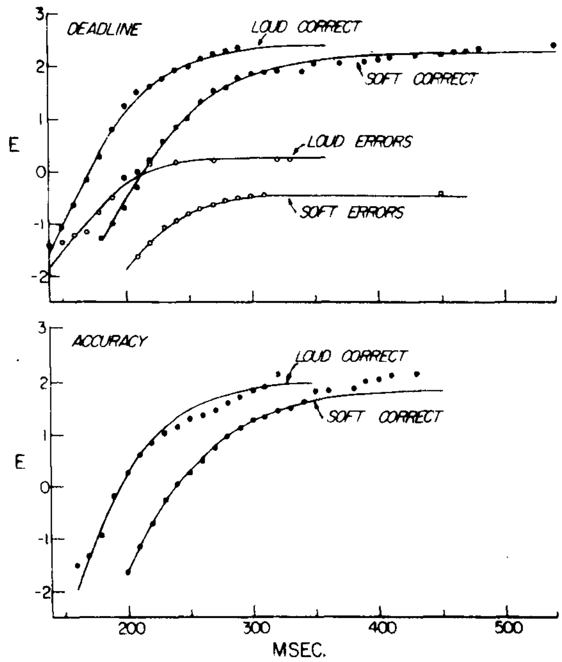

Figure 4. E as a function of time for Subject 2, for all stimuli in the deadline condition and the correct stimuli in the accuracy condition. The smooth curves for the deadline condition are the appropriate combinations of the functions from Figure 3. For the accuracy condition, they are the sensory growth functions from simple RT, with the linear transformation representing the criterion change.

are presented in the upper panel of Figure 4. The data points plotted are the average scale values from the actual distributions. If this was to be viewed as a mere curve fitting exercise, it was obviously successful. It is certainly intended to be considerably more than that—a quantitative and analytic description of the psychological processes upon which this performance was based. It should be emphasized that the sensory growth functions, providing the basis for the analyses of both the accuracy and deadline conditions, did not come from this set of data but from simple RT performance.[3]

For readers unfamiliar with previous similar analyses of variable criterion theory, one property of Figure 4 may be noted. If a normal curve were erected vertically with unit σ and the mean at zero, areas of the curve below the functions at each point on the time axis would generate computed probability distributions for each stimulus. These would be for the session on which the present scale was based. Distributions for other sessions would be generated by normal functions with the estimated values of σ and means at the estimated values of T.

The results of a similar analysis upon the data of Subject 4 are presented in Figures 5 and 6. In this case the V functions were derived from four sessions in the 1/3 simple RT condition and the accuracy and deadline data were from two sessions in each condition. In this instance, the single regression line relating the accuracy scale values to the computed values of the two V func-

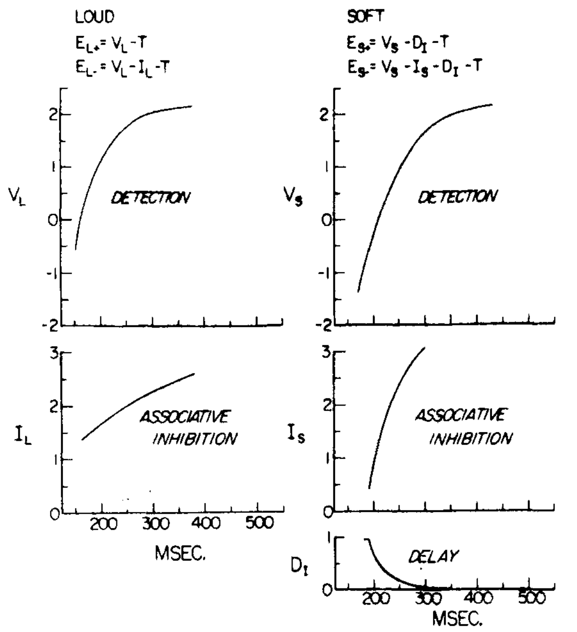

Figure 5. Graphs of the component functions for Subject 4 in the deadline condition.

tions accounted for 99.3% of the variance in the accuracy data. The two functions with the common linear transformation are presented with the accuracy data points in the lower panel of Figure 6. Considering that there were only two parameters estimated from the data, this is a remarkable fit, and is taken as strong evidence that the subject was responding to detection information with only criterion changes.

The component functions for the deadline condition are presented in Figure 5. The REC relating the loud scale values to V_L accounted for 99.2% of the variance. The delay strategy for the soft stimulus was greater in amount than for Subject 2, but began to decline earlier. The growth of associative inhibition was more rapid than for Subject 2. It seems probable that the initial high level of the I_L function is due to sampling error in the unreliable tail points of the error distribution. The computed E functions in the upper panel of Figure 6 provide an excellent description of the deadline data.

Subject 5 was the other member of this class. Here the V functions were based on four sessions from the 1/10 simple RT condition and two from the 1/3 condition. Two sessions were included from the accuracy condition and three from the deadline condition. The line relating accuracy performance to the two V functions accounted for 98.7% of the variance, and the resulting functions are presented in the lower panel of Figure 8. An interesting feature of the subject's performance was that a partial analysis of his first two sessions indicates that he began with an approximation of the positive associative strategy, to be described later, and shifted to this type of performance.

The most interesting feature of Subject 5's performance in the deadline condition was his exaggerated use of delaying response to the soft tone, a strategy which he clearly verbalized at the end of the experiment. The initial level of his delay inhibition was 1.628 scale units, and it remained constant until 280 msec. The regression line relating the loud scale values to V_L accounted for 99.3% of the variance. For the relation of the soft scale values to V_S, an exactly parallel line displaced downward by 1.628 units accounted for 98.0% of the variance of the first nine points up to 280 msec.

The subsequent increase in response strength above this line was best described by a Gompertz function with initial positive acceleration. This strategy was so successful that a total of only four errors were made in response to the soft catch signal in the three sessions analyzed. As a result, no estimate of the soft associative inhibition function could be made. The remaining component functions of the model are presented in Figure 7 and the resulting combined functions are in the upper panel of Figure 8.

Evidence for Positive Association

Our first evidence concerning the positive associative process is from Subject 1, who produced the most consistent performance of the five subjects. In this case the sensory detection functions are based upon four sessions from each of the two simple RT conditions. The disjunctive accuracy data comprise four of the five sessions, and the deadline data consist of all five sessions. The solution here was made jointly for the speed and deadline data rather than separately as in the previous examples. The first step was the plot of RECs relating

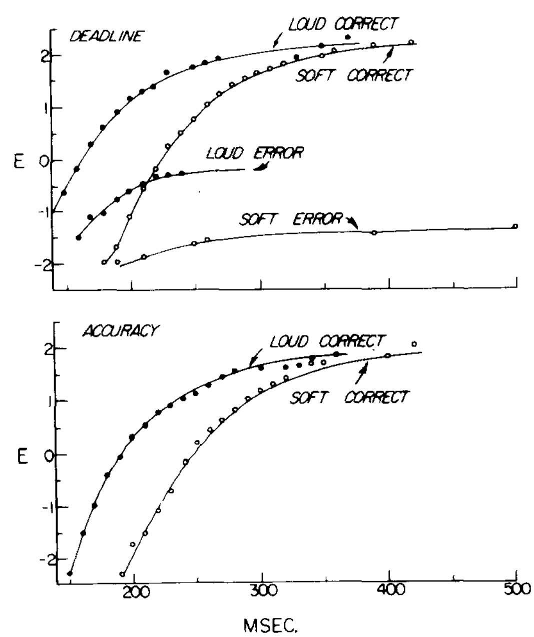

Figure 6. E as a function of time for Subject 4 in the deadline and accuracy conditions.

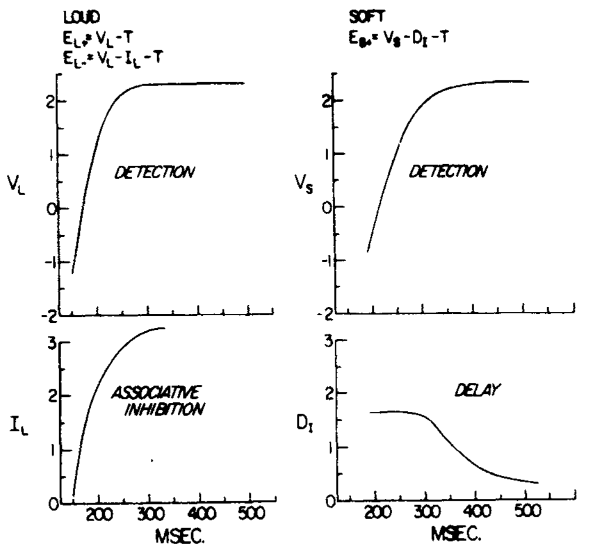

Figure 7. Graphs of the component functions for Subject 5 in the deadline condition.

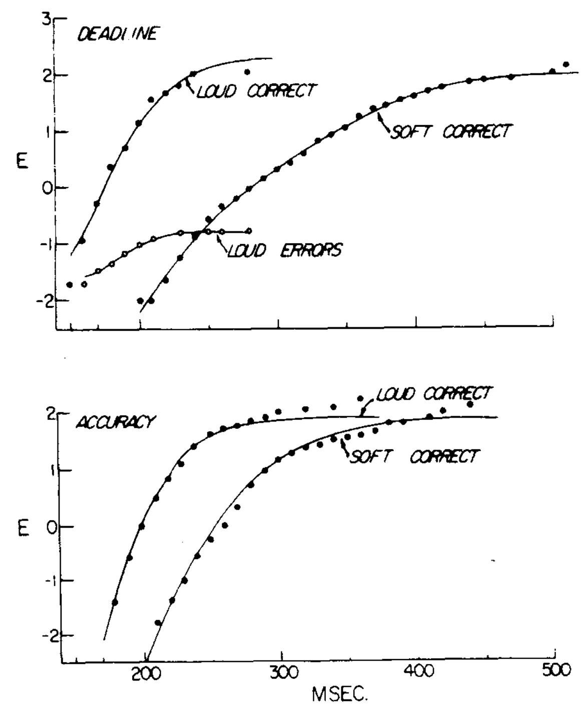

Figure 8. E as a function of time for Subject 5 in the deadline and accuracy conditions.

the deadline and accuracy average scale values for the two intensities. These are presented in Figure 9. The loud function is linear, indicating normality and consistent use of the stimulus information in both conditions. The soft function is also linear and parallel up to 320 msec. The interpretation of this picture is that the parameters of the loud function estimate the between-conditions σ ratio and the difference in mean criterion level. The slope of the linear portion of the soft function also estimates the σ ratio. The difference between the intercepts is the initial constant level of the delay inhibition resulting from the presence of deadline signals for loud only. The final departure from linearity in the soft function is the relaxation of inhibition observed in the previous subjects. The fitted lines are parallel with the mean slope of the two mutual least squares lines. They pass through the means as conventional regression lines. The loud function accounts for 99.5% of the two-condition variance. The soft line, to 320 msec, accounts for 99.7%. This is remarkable considering that neither is a best-fitting line.

The next objective was to obtain joint estimates for the two conditions of the functions indicating the growth of E, with the special delay inhibition excluded from the soft data of the deadline condition. From these functions, the more general information processing functions are derived. The time function of the soft delay inhibition was derived in the same manner as with the preceding subjects. This is the bottom curve at the right of Figure 12. This was then added to the deadline soft data at 10-msec intervals. With this correction, the REC of Figure 9 now becomes a single line with the slope and intercepts of the loud function. Using this linear transformation, the accuracy data were then converted to the scale of the deadline condition. On this common scale, the values for accuracy and deadline were then averaged at 10-msec intervals throughout the range of the functions for both loud and soft.

As in the previous analyses, these combined disjunctive scale values were next plotted against computed values of the two sensory detection functions derived from simple RT. In this instance, the two intensities produced a common linear function up to 220 msec only. This REC is presented in Figure 10. In this short latency region, the common linear regression with V_L and V_S accounted for 98.8% of the variance in the disjunctive scale values. This implies that up until 220 msec the subject was responding entirely upon the basis

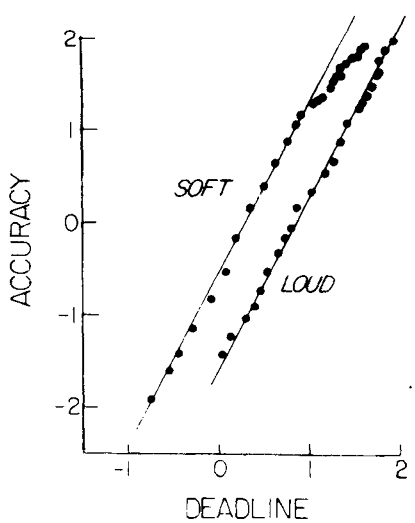

Figure 9. RECs for Subject 1 relating scale values of the accuracy and deadline conditions. The lines are of equal slope. Points are at 10-msec intervals.

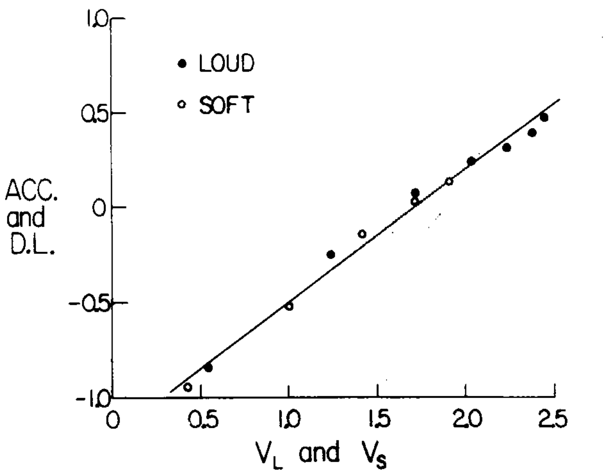

Figure 10. REC for Subject 1 relating mean scale values of the deadline and accuracy conditions to computed values of the V_L and V_S functions from simple RT up to 220 msec. Points are at 10-msec intervals. The ordinate is on the scale of the deadline condition.

of detection information, with criterion parameters implied by the slope and intercepts of the regression line. Beyond 220 msec, both the loud and soft functions began to rise progressively above the line in a curvilinear fashion. This implies that at this time the subject was beginning to respond on the basis of a different source of information not revealed in analysis of the previous subjects. Since the earlier information growth is identified as pure detection, it is the obvious inference that this later process is associative strength to the positive stimuli. This inference is strengthened by the fact that there was no such phase of late growth in the error functions. In other words, it is specific to the positive stimuli.

Functions describing the growth of associative strength were then derived. The additive model, used by Grice (1972a) with conditioning data was applied: $E = H + V - T$. Since T is at zero on the present scale, $H = E - V$. To obtain the values of V, the two detection functions (V_L and V_S) were transformed to the scale by means of the parameters of the REC of Figure 10. These computed values of V_L and V_S were then subtracted from the corresponding values of E_L and E_S at each 10-msec interval. These differences will necessarily cluster around zero in the linear range of the REC, and provide estimates of the growth of H beyond that. These estimates of H are the data points in Figure 11. It is obvious that very regular functions were produced, increasing with initial positive and final negative acceleration. As in the case of associative inhibition, soft associative strength was somewhat superior, but the two functions are very similar. They have been fitted with Gompertz growth functions which account for 99.2% of the variance of the data points in Figure 11.

The error functions from the deadline condition of Subject 1 were analyzed in the same manner as for the previous subjects. There also was clear evidence of associative inhibition with respect to response to the negative stimuli, although it was less than in subjects relying purely on the inhibitory strategy. It also grew as negatively accelerated functions, but the rising portions were less regular than for the previous subjects, resulting in relatively poorer fits to the error functions. It is our impression that this was the result of rather inconsistent use of associative inhibition between sessions.

The component functions of the model for both the accuracy and deadline conditions are presented in Figure 12. The basic equations of the model are also included. Functions describing the growth of E for the two conditions are presented in Figure 13. Data points are the average scale values derived from the cumulative distributions for each stimulus. The smooth curves are obtained from the appropriate additive combinations of the computed component functions. It is clear that a rather adequate description of this complex performance has been obtained. The shift from dependence on detection information to postitive association produced bimodality in the RT distributions and may be observed here as inflections in the growth curves. This is more prominent for the loud stimuli, where the initial rise of V is more rapid.

The results of a similar analysis for Subject 3 are presented in Figures 14 and 15. Here the data were four sessions from the 1/3 simple RT condition, two from the accuracy condition and three from the deadline condition. The general features of this analysis are similar to those of Subject 1. The fact that no clear bimodality was observed appears to be related to slower rising detection functions. The fitted loud association function suggests an origin before 200 msec, but the first empirical value of H above zero was at 200 msec. This subject has shown greater differential sensitivity than other subjects to signals of 100 and 50 dB in both this and the previous experiment. This suggests a mild

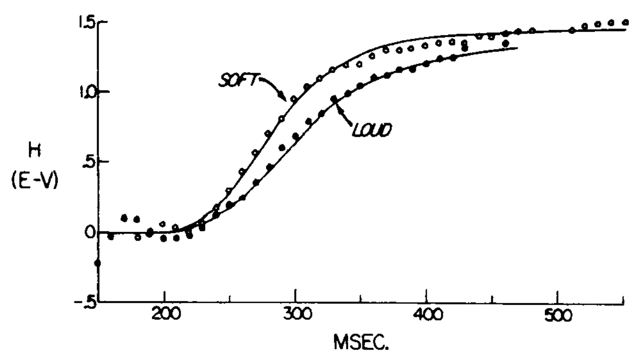

Figure 11. Data points and fitted Gompertz functions indicating the growth of positive associative strength for Subject 1. The scale is that of the deadline condition.

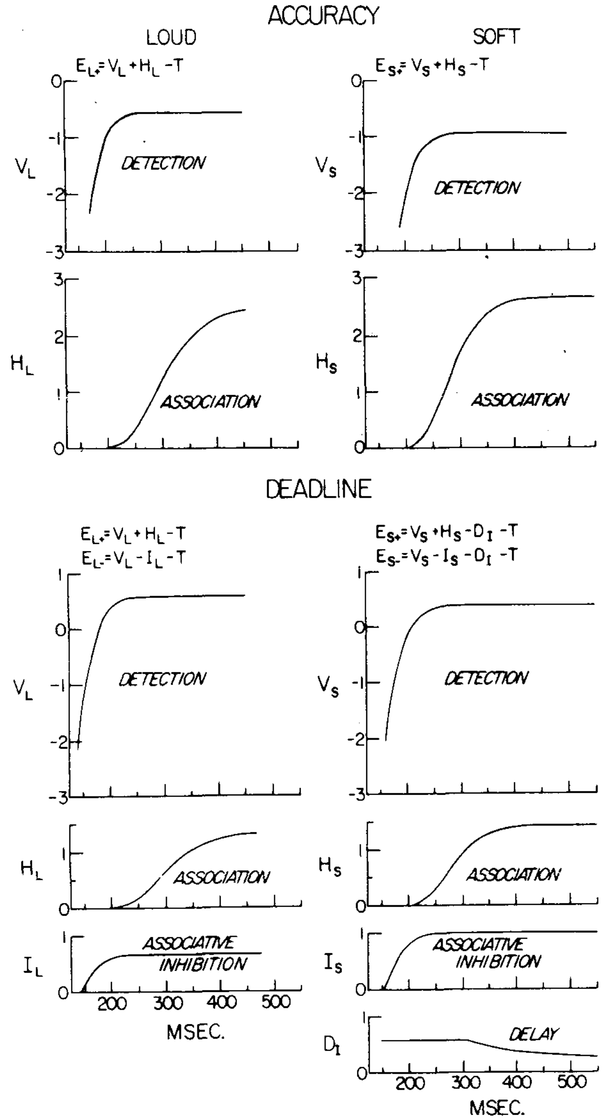

Figure 12. Component functions of the model of Subject 1 for the accuracy and deadline condition. The detection and positive association functions are the same for the two conditions except for the linear transformation reflecting the different criterion parameters.

hearing loss which may be related to the later start of soft positive association. Associative inhibition played a larger role in the performance of this subject than in the case of Subject 1, but his strategy still depended substantially upon positive associative strength. This subject was the only one not clearly showing delay inhibition to the soft stimuli in the deadline condition. However, the several short latency points below the soft E function suggest that the process was present to some degree. They suggest that it first increased and then decreased in the range from 190 to 240 msec.

Criterion Effects and the Speed-Accuracy Tradeoff

The criterion parameters for all sessions analyzed are presented in Table 1. The criterion means (T) are the means of all analyzed sessions in each condition. They have been adjusted to a scale with zero as the mean of a simple RT condition. The unit is that of the scale on which the V functions were determined. The standard deviations are the total σs for each condition. They were obtained by pooling the within-session variances and adding the variance of the session means. They were then adjusted to unity for a simple RT condition. Each value gives the ratio of a condition σ to that of simple RT.

The general picture with respect to mean criterion level is as expected. In all cases, the level in the disjunctive/accuracy condition is elevated well above that for either simple RT or the deadline condition. This indicates that, irrespective of the strategy used in responding to the stimulus information, the tradeoff was accomplished by criterion adjustment. The criterion then is determined by task requirement. It is raised in the disjunctive condition by the requirement to respond associatively, and then decreased by the deadline requirement.

There is also an interesting and consistent pattern in the condition σs. For all subjects, the highest criterion level in the accuracy condition was also accompanied by the smallest σ. This suggests the possibility of another kind of tradeoff. It appears that maintaining a low mean criterion level is accomplished at some cost of criterion consistency. In general, this will produce more long latency responses in the upper tail of the RT distribution and a higher error rate than if the same level of criterion variability could be maintained.

As a summary of the RTs themselves, the medians and interquartile ranges (Q), in milliseconds, are pre-

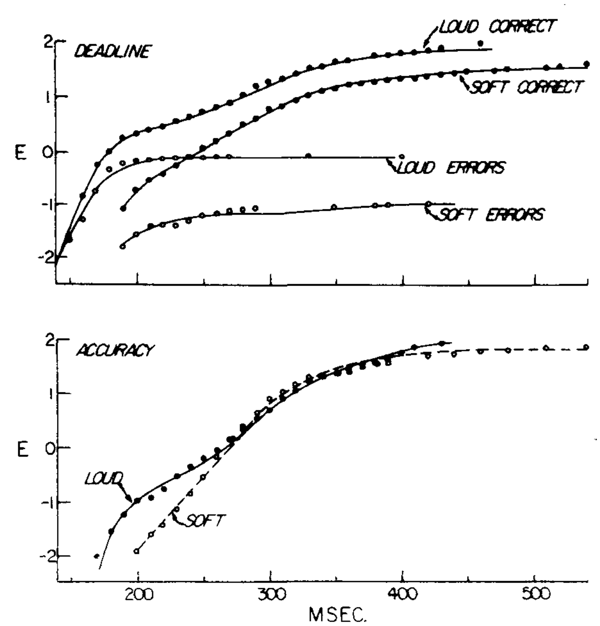

Figure 13. E as a function of time for Subject 1 for all stimuli in the deadline condition and the correct stimuli in the accuracy condition. Smooth curves are the appropriate combinations of the component functions of Figure 12.

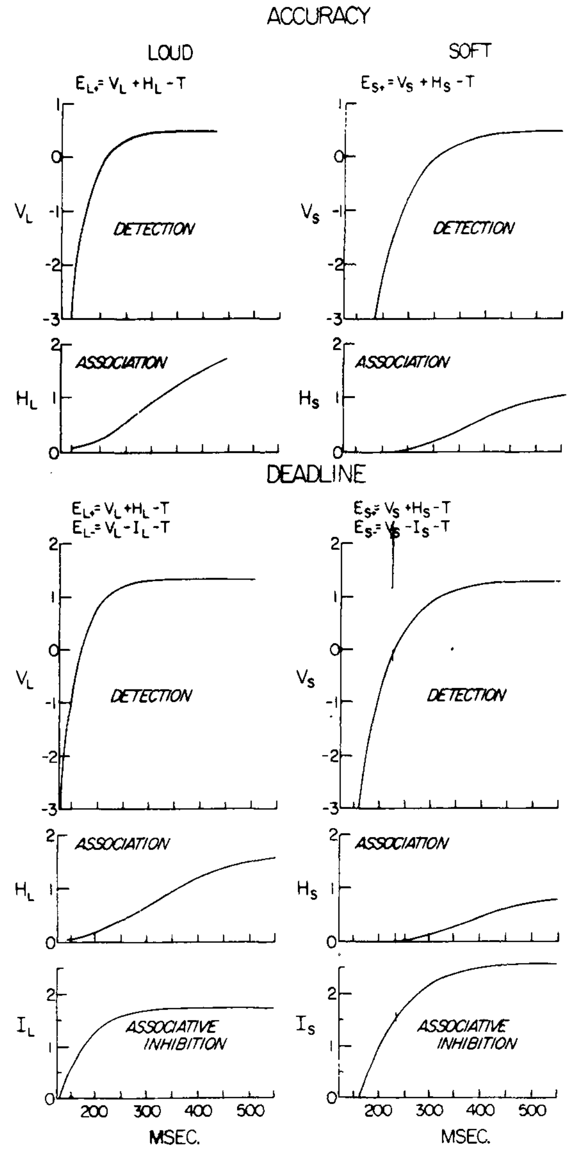

Figure 14. Component functions of the model for Subject 3 for the deadline and accuracy conditions.

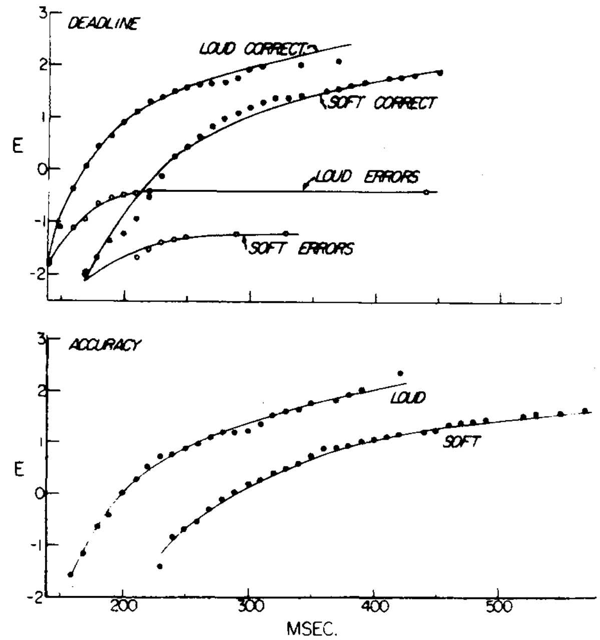

Figure 15. E as a function of time for Subject 3 in the deadline and accuracy conditions.

sented in Table 2 for all analyzed data. The error rates are also presented for the deadline condition. As expected, the disjunctive/accuracy condition consistently produced the longest latencies. The usual strong within-subjects intensity effect appears in all cases, except for Subject 1 in the accuracy condition. In this instance, both medians fell in the range of positive associative growth and were relatively unaffected by sensory strength.

Perhaps the most interesting finding with respect to median RT is that for the inhibitory strategy subjects, at least, errors in the deadline condition were not of shorter latency than correct responses. Shorter latency for errors is the usual finding in choice RT, and has also been obtained with the c reaction (Gibson, 1939). However, this appears not to be a necessary property of the c reaction when the inhibitory strategy is used. The situation is less clear for the positive association subjects, since the medians are in the sensory recruitment range or early in the positive association phase and do not reflect the long latency responses in the upper tails. Means have not been regarded as appropriate statistics for the present data, but were computed here. Errors averaged 44 msec faster than correct responses for Subject 1, and 19 msec faster for Subject 3. For the inhibitory strategy subjects, means showed the same result as the medians.

The common positive relation between RT and its variability, when signal intensity is varied, appears in all

Table 1
Mean and Standard Deviation of Criterion for Each Condition

	1/10 Simple			1/3 Simple			Accuracy			Deadline		
Subject	Number of Sessions	Mean	SD	Number of Sessions	Mean	SD	Number of Sessions	Mean	SD	Number of Sessions	Mean	SD
2	5	0	1.000				2	1.187	.652	4	.362	.948
4				4	0	1.000	2	.915	.835	2	.320	1.346
5	4	0	1.000	2	.348	1.004	2	.949	.826	3	−.802	1.251
1	4	0	1.000	4	.437	.949	4	2.814	.708	5	1.667	1.361
3				4	0	1.000	2	2.389	.739	3	1.191	.931

Note—Subjects 2, 4, and 5 used the inhibitory strategy; Subjects 1 and 3 also used positive association.

Table 2
Median RTs and Interquartile Ranges (Q) for Each Condition

Subject		1/10 Simple Mdn	1/10 Simple Q	1/3 Simple Mdn	1/3 Simple Q	Accuracy Mdn	Accuracy Q	Deadline Correct Mdn	Deadline Correct Q	Deadline Errors Rate	Deadline Errors Mdn	Deadline Errors Q
2	Soft	208	32			251	50	224	41	.235	244	48
	Loud	174	31			201	37	182	27	.470	191	27
4	Soft			220	34	247	42	225	38	.070	243	49
	Loud			170	29	193	40	164	30	.390	188	43
5	Soft	237	38	246	37	269	44	279	74	.020	295	125
	Loud	186	21	193	31	205	28	172	23	.240	188	40
1	Soft	177	17	186	22	267	44	250	87	.128	245	62
	Loud	157	14	162	18	266	71	183	85	.440	173	18
3	Soft			208	48	295	85	237	44	.080	230	30
	Loud			157	24	203	45	172	36	.287	173	25

Note–Subjects 2, 4, and 5 used the inhibitory strategy; Subjects 1 and 3 also used positive association.

cases but one. The exception, which is large, is both interesting and instructive. In the case of Subject 1 in the accuracy condition, the first quartile (Q_1) for the loud signal was early and determined entirely by sensory strength, while the third quartile (Q_3) was later in the associative growth phase. Because of slower sensory growth, both Q_1 and Q_3 for the soft signal were in the associative growth phase, producing smaller variability. With the lower criterion of the deadline condition, Q_1 fell in the sensory growth phase for both stimuli, producing large and approximately equal variability.

DISCUSSION

The present findings appear to have produced a substantial gain in our understanding of the psychological processes involved in this type of performance. The identification of two associative processes rather than one should not be viewed with great surprise. Upon the basis of the analysis of the Grice et al. (1974) data, we had expected to find the positive associative process. However, in a yes-no situation with two stimuli, it is logically necessary for response to be determined associatively only with respect to either of the stimuli–not necessarily the positive one. Users of the inhibitory strategy may respond to the positive stimulus purely upon the basis of detection if the criterion is sufficiently high that they may rely upon their ability to inhibit response to the negative stimulus. To the degree that the criterion is not sufficiently high, the speed-accuracy tradeoff will be produced. Generally, the inhibitory strategy appeared to be the more efficient one in the present task, permitting response on the basis of the more rapidly growing sensory information and producing lower variability. Inhibition is a very rapidly growing process, but there is other evidence for its speed in RT tasks. For example, Lappin and Eriksen (1966) presented a second signal, countermanding the go signal, at various intervals following the go signal. They found that RT need be extended only a few milliseconds beyond the delay interval to obtain reliable inhibition. For all subjects in the present experiment, associative inhibition grew as a negatively accelerated function. However, there were differences in the rate and extent of growth, indicating individual differences in the utilization of this skill. Now that this process has been identified and, at least in a preliminary way, measured, further research concerning its properties and the circumstances of its use is obviously indicated.

In the case of the subjects identified as using the positive, associative strategy, it should be noted that associative inhibition also played a role in their performances, more so for one subject than the other. However, the H functions derived were of such regularity that they certainly must be taken seriously as describing the growth of associative strength. Beginning at about 200 msec, or a little later, all were inflected functions of final negative acceleration. There was no evidence of response evocation on the basis of positive association at latencies less than 200 msec. It is interesting and possibly important to note that this was also Grice's (1972a) finding for human eyelid conditioning. Another interesting feature of these subjects' performance was that there was no later rise in the error functions corresponding to the growth of positive association for the correct responses. This implies that the stimuli were sufficiently dissimilar that there was no measurable stimulus generalization with respect to positive association. Errors were produced entirely by response to detection information on trials when inhibition was insufficient. Thus, the model presented contained no positive association component for the negative stimuli, and associative inhibition subtracts only from sensory strength. We presume that the situation will be different when more similar stimuli are used. In fact, Grice's model for differential eyelid conditioning did require an associative component for the negative stimulus in the range above 200 msec. In the long run, it is probable that positive association can be studied better in choice RT than in the c reaction.

According to these analyses, the basis of the speed-accuracy tradeoff was entirely the obvious one from the point of view of variable criterion theory—the adjustment of criterion level. In the case of the inhibitory strategy, higher criteria result in response at later stages of sensory growth, thus allowing more time for the development of associative inhibition if the signal should be negative. In the case of the positive strategy, higher criteria also result in response at greater levels of positive associative strength. We assume that this is the major factor in choice RT. It should also be noted that, from the point of view of variable criterion theory, the tradeoff is not merely a between-conditions process. Since the criterion varies from trial to trial, it is potentially present within any experimental condition. If the criterion mean is sufficiently high, and the variability sufficiently low, error-free performance may result.

In the case of subjects with the positive associative strategy, especially Subject 1 with bimodal performance, there is a natural tendency to consider the possible application of the fast-guess model (Ollman, 1966; Yellott, 1967, 1971). The hypothesis would be that the early responses were fast guesses. It seems clear, however, that the fast-guess model will not describe these data because the error rate in the short latency range is too low for these responses to be pure guesses.

The present discovery of two associative processes and the two related strategies may resolve a question raised by the Grice et al. (1974) research. Grice (1972b) reported an analysis of an auditory RT experiment by LaBerge (1971), in which the experimental variable was the nature of catch trial events. Grice's analysis indicated that the data could be fully described by a single function indicating sensory growth, and criterion parameters which depended upon the nature of the catch trial. However, in the Grice et al. (1974) data, the growth functions were not the same in conditions which did or did not involve auditory catch signals. It now seems possible that, in the more simple task used by LaBerge, subjects were able to perform consistently with the inhibitory strategy. In the later experiment, however, the process of positive association was involved.

Several points of strategy in the design of theoretical research such as this should be emphasized. One of these is the inclusion of a simple RT condition from which the sensory detection functions may be derived. This permits determination of the role of this process in the more complex task and the analytic separation of other processes. Since the model used here was an additive one, this suggests a superficial similarity to the logic of the Donders subtractive method. However, we do not concur that the component processes are sequential or that their durations may be meaningfully specified by subtractive time constants. On the contrary, our analyses indicate that the underlying processes are continuous functions of time and that they are parallel rather than serial. The duration of any of these processes on a particular trial will depend upon the level of the criterion on that trial. This, in turn, depends upon the mean and variability parameters of the criterion distribution.

Another frequent point of good strategy is the inclusion of the stimulus intensity variable. Of course, this gives added information concerning the nature of sensory growth. But when the same between-condition or between-session criterion parameters may be estimated from each intensity, it is strong evidence for consistent performance and for the validity of the estimates.

An additional important design consideration is the use of experimental conditions which produce high error rates and the speed-accuracy tradeoff. Considerably more evidence concerning the underlying processes is present in such data than in highly accurate performance. For example, it now appears likely that LaBerge's (1971) subjects were using the inhibitory strategy, but we were not able to understand the matter or describe the inhibitory process until the present investigation. This same point concerning the importance of obtaining tradeoff information has recently been made by Wickelgren (1974) in connection with investigations of the dynamics of a variety of information processing tasks. While his proposed experimental and analytic procedures for obtaining speed-accuracy tradeoff functions differ from the present approach, his basic argument is the same. In fact, studies comparing the methods he recommends (e.g., Reed, 1973) with the present ones may provide an important source of converging evidence.

The present research should not be confused with an experimental test of a precisely formulated theory. The present status of this enterprise is that of theory development. Variable criterion theory provides measurement and analytic techniques which aid in the identification of theoretical processes and in the discovery of laws relating them to empirical variables and to each other. It does appear that the framework of a more comprehensive theory is beginning to emerge.

REFERENCES

Gibson, E. J. Sensory generalization with voluntary reactions. *Journal of Experimental Psychology*, 1939, **24**, 237-253.

Grice, G. R. A threshold model for drive. In H. H. Kendler & J. T. Spence (Eds.), *Essays in neobehaviorism: A memorial volume to Kenneth W. Spence.* New York: Appleton-Century-Crofts, 1971. Pp. 285-310.

Grice, G. R. Conditioning and a decision theory of response evocation. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 5). New York: Academic Press, 1972, Pp. 1-65. (a)

Grice, G. R. Application of a variable criterion model to auditory reaction time as a function of the type of catch trial. *Perception & Psychophysics*, 1972, **12**, 103-107. (b)

GRICE, G. R., HUNT, R. R., KUSHNER, B. A., & MORROW, C. Stimulus intensity, catch trial effects, and the speed-accuracy tradeoff in reaction time: A variable criterion theory interpretation. *Memory & Cognition*, 1974, **2**, 758-770.

LABERGE, D. On the processing of simple visual and auditory stimuli at distinct levels. *Perception & Psychophysics*, 1971, **9**, 331-334.

LAPPIN, J. S., & ERIKSEN, C. W. Use of a delayed signal to stop a visual reaction-time response. *Journal of Experimental Psychology*, 1966, **72**, 805-811.

OLLMAN, R. Fast guess in choice reaction time. *Psychonomic Science*, 1966, **6**, 155-156.

REED, A. V. Speed-accuracy tradeoff in recognition memory. *Science*, 1973, **181**, 574-576.

WICKELGREN, W. A. Speed-accuracy tradeoff and information processing dynamics. *Bulletin of the Psychonomic Society*, 1974, **4**, 249.

YELLOTT, J. I., JR. Correction for guessing in choice reaction time. *Psychonomic Science*, 1967, **8**, 321-322.

YELLOTT, J. I., JR. Correction for fast guessing and the speed-accuracy tradeoff in choice reaction time. *Journal of Mathematical Psychology*, 1971, **8**, 159-199.

NOTES

1. The exact proportion of total variance in x and y accounted for by the mutual regression line is given by the expression:

$$\frac{\sigma_x^{2\prime} + \sigma_y^{2\prime}}{\sigma_x^2 + \sigma_y^2} = \frac{2\,\mathrm{cov}_{xy}\,(S + 1/S) - S^2\sigma_x^2 - \sigma_y^2/S^2}{\sigma_x^2 + \sigma_y^2},$$

where $\sigma_x^{2\prime}$ and $\sigma_y^{2\prime}$ are the amounts of variance in x and y accounted for by the line and S is the slope of the line. In addition to its usual interpretation, r^2 also gives the proportion of total variance in x and y accounted for by the two unidirectional regression lines, but overestimates the value for the single line. However, since the slopes of the two lines approach that of the single one as r increases, the bias is small for high correlations. For the data included here the bias does not exceed .001. For the present mean value of r^2 it is .0004.

2. Unequal σ scaling solutions of this kind have been presented in several papers of this series beginning with Grice (1971). Along the axis of the fitted REC line is a dimension of increasing response strength (E) which is related to the independent or dependent variable used to determine the points. In the case of an REC based upon two cumulative latency distributions, the variable is time and the function derived gives the growth of E with respect to time. Each empirical point vector contains two estimates of the value of E at that time. The joint estimate may be obtained from the coordinates of the projection of the point on the line. The y element of the projection gives the value of E on the y scale and the x element gives it on the x scale. However, it is usually simpler to convert either the x or y element to the scale of the other and take the mean. This is particularly true when more than one REC is involved and the estimate of each value on the dimension is to be based on a mean of more than two values. In this case, conversion to a single scale is performed sequentially. A convenient analogy to this type of scaling is the conversion in either direction between the Fahrenheit and Celsius scales, an example where both unit size and the origin differ. A specific case would be one in which one desired the mean reading of two thermometers of different types.

3. It may be noted that the detection functions of Figure 3 and those in subsequent figures are shown as beginning at about 150 msec. No theoretical significance is attached to this. This is merely the time of the shortest latency responses in the present task. There were shorter latency responses and some extension of the functions in the simple RT conditions from which they were derived. So far, it has not been possible to determine a meaningful absolute zero for the sensory functions or to specify a theoretical value for an "irreducible minimum" RT. One possible approach to this would be to locate a point at which the detection functions for all intensities might intersect. However, the lower portions of these functions are based on only the extreme tails of the distributions and are consequently less reliable than other portions. For this reason, extrapolation of the current functions is not useful. It appears that a solution of this kind would require a larger quantity of data than is collected in ordinary research.

A related problem is that of the time required for the response process itself, a matter with which the model does not presently deal. The appropriate place for the insertion of this time would be at the point at which E reaches the criterion. At present, however, it is included in the delay prior to the origin of the detection functions, so they are theoretically late by this amount. A theoretical irreducible minimum should be any absolute delay in the origin of the detection function plus response time.

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