NASA CR-454

FURTHER EXPERIMENTS ON SUCCESSIVENESS DISCRIMINATION

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Prepared under Contract No. NAS 2-2486 by
BOLT BERANEK AND NEWMAN, INC.
Cambridge, Mass.

for Ames Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FURTHER EXPERIMENTS ON SUCCESSIVENESS DISCRIMINATION

Introduction

The probability that two independent sensory signals will be discriminated as successive rather than simultaneous is a function of the amount of time which separates them. Under certain conditions this functional relationship is described quite well by a straight line like the one in the right half of Figure 1. In this figure the probability of a correct discrimination is plotted against the interval which separates the two signals.

Values of P(C) are obtained with a two-choice forced-choice psychophysical method. A pair of signals consists of the offsets of a light and a tone and two such pairs, presented successively, make up a trial. In one of the pairs the offsets are simultaneous; it is called the standard. For the other pair, the variable, the offsets occur successively. The subject is asked to try to identify the variable by indicating whether it was presented first or second, and P(C) is the proportion of trials on which this is done correctly for a particular value of the interval separating the signals which comprise the variable. This probability has a range from .50 to 1.00 since the subject may be correct half of the time entirely by chance.

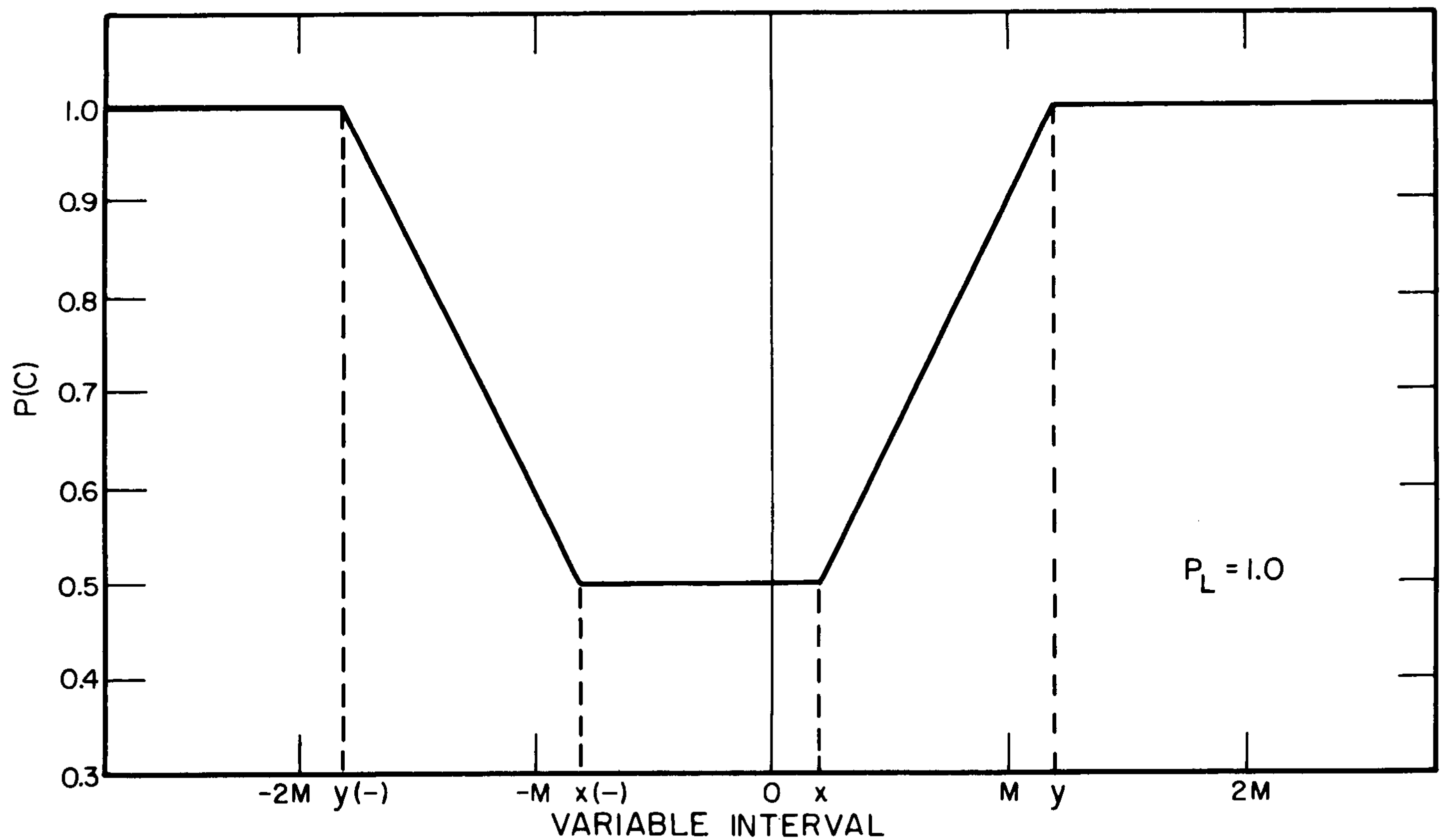


FIG. 1 EXPECTED FORM OF THE SUCCESSIVENESS DISCRIMINATION FUNCTION BASED UPON ATTENTION THEORY. STANDARD = 0, $x = 0.2$ M, $P_L = 1.0$

One additional point needs to be clarified concerning the construction of Figure 1. Values of the variable interval which are greater than zero mean that the light signal occurs before the tone by the indicated amount. Negative values mean that the auditory offset happens first.

All of the measurements we have made to date (1,2) have been concerned only with determining the ascending segment in the right half of Figure 1, that is, the discrimination of positive intervals from a standard of zero. Most such sets of data are described adequately by a straight line (2). Typically, the line intersects the chance baseline at about 10 msec. and rises to 1.0 at about 60 msec. The former value, 10 msec., is called x and the distance spanned by the ascending limb, approximately 50 msec., is called M.

A specific theoretical interpretation of these parameters has been given (2,3) in which x is taken to be the difference between the two sensory channels in the time required to transmit the message from the signal source to the neural display areas. When the visual signal precedes the auditory signal by x msec., the two neural inputs arrive simultaneously in their respective display areas. The fact that x is positive implies slower conduction in the visual channel.

The second parameter, M, is thought of as the period of an internal timing mechanism which emits a series of equally-spaced temporal points. One of these points occurs every M msec. and they determine whether a pair of signals can be coded as successive rather than simultaneous. If one point falls in the interval between the signals which occur in the display areas, then the signals may be coded as successive. Since the pair of signals may fall anywhere on the time continuum with respect to the internally-generated temporal points, the probability that one point will fall between the signals will be zero when the external signals are separated by x and it will be unity when they are separated by (x + M), the value denoted by y in Figure 1. When the variable interval is y, the neural signals will be separated by M and exactly one point will fall between them on every such trial. In general, the probability that a point will fall between the neural signals produced by signals which are separated by I msec. is

$$\frac{I - x}{M}$$

Postulating an internal clock of this sort does seem to be unreasonably simple, and at variance with the complexity we expect to encounter in quantitative psychological work. Nonetheless, the notion does have some support. In a recent report (3), three independent behavioral methods of measuring the period of the clock have been described which yield data which are in good quantitative agreement.

Why should an interpolated temporal point be necessary for the discrimination of successiveness? One possibility which has been discussed in detail earlier (2,3) is that one of the functions of the internal clock is to control the switching of attention among input channels in the sense that attention can, but need not, switch from one channel to another only when a point occurs. In order to discriminate two independent neural events as successive, it is necessary to observe the occurrence of one, switch attention to the channel which contains the second, and then observe the occurrence of the second. If the second event has already occurred by the time the switching operation is completed, then the two events are equivalent to simultaneous events.

This explanation clearly supposes that the subject is attending to the channel which contains the first signal at the moment the first signal occurs and then switches to the second channel without fail when the next opportunity comes along. If, for example, the subject were attending to the channel of the second signal when the first signal occurs, then it would be necessary to switch to the first channel and then back to the second channel during the interval between the signals in order to discriminate them as successive. Two points would have to occur during the interval in such a case.

If this explanation is correct, then there is another theoretical parameter which is of importance, viz. the probability that the subject is attending to the channel which contains the first signal at the moment the first signal occurs. In Figure 1, it is assumed that $P_\ell = 1.0$. Under this assumption, it follows that all intervals in the range between x and (x - M) should be equivalent and they should all yield only chance performance. This is because they all produce pairs of neural signals which have only either zero or one point between them; and, since $P = 1$ and the first event for intervals in this range is auditory, two points are required for a correct discrimination.

Finally, as the interval is made larger in the negative direction below x(-), the proportion of trials on which the required two interpolated points occur increases, reaching unity at y(-) = x - 2M.

According to this theory, the shape of the function should change as a function of P_ℓ in the manner illustrated in Figure 2. It is evident that P_ℓ must be controlled if a precise measurement of M is to be obtained. Further, since x is positive and the standard is zero, the best chance of determining M without bias lies in making every attempt to maximize P_ℓ. These are the reasons why only positive variable intervals have been used in the first experiments. By having the visual signal be the first signal in every variable pair, the subject can maximize P(C) by attending to the visual channel, i.e., by maximizing P_ℓ.

<u>An alternative interpretation</u>.- The preceding analysis has been couched in the concepts of the theory of attention out of which this work has grown. There is another way of thinking about the same relationships which is worth considering as an alternative theory. This alternative, which might be called a "counting model" of time discrimination, retains the central idea of a fixed-period time point generator and simply postulates that the psychological duration of an interval defined by two independent sensory signals is equal to the number of time points which fall between the display area events which correspond to the signals.

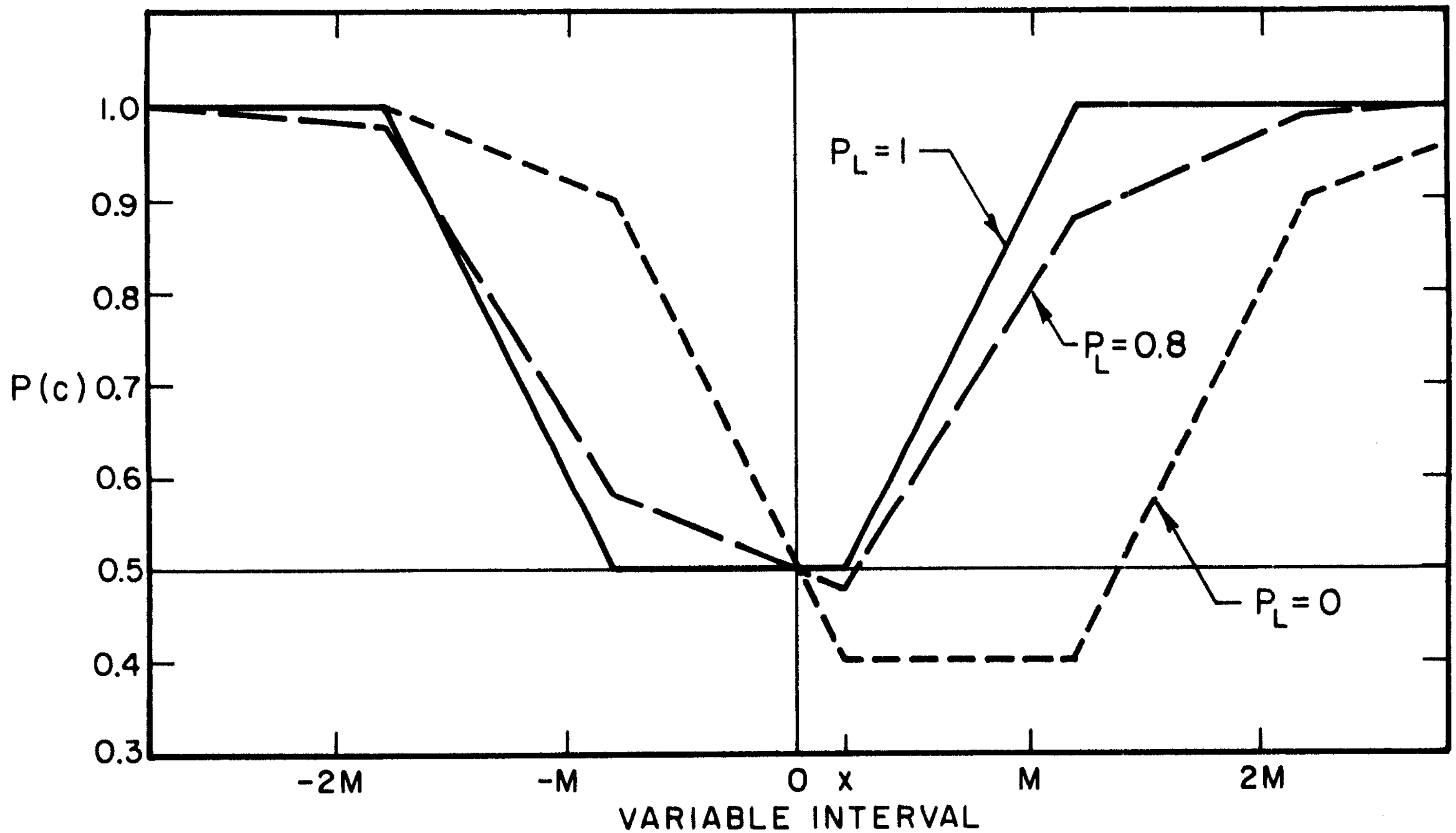


FIG. 2 THE PREDICTED EFFECT OF CHANGES IN P_L UPON THE SUCCESSIVENESS DISCRIMINATION FUNCTION OF FIG. 1

If the parameter x retains its previous meaning, then an interval of duration x would always be counted (0) and an interval of (x + M) would always be counted (1). Intervals between x and (x + M) would be (0) on some trials and (1) on other trials, the probability of a (0) being

$$\frac{I - x}{M},$$

in which I is the interval of interest within the range.

An interval, however, carries another potentially useful item of information: order. Thus, referring to the same experimental arrangement as before, an interval which contains one time point will be called (+1) if the light terminates first and (-1) if the sound terminates first.

It is obvious that order information is given by intervals which are greater than some duration but it may not be carried by very short intervals. For example, it may be that an interval which is coded (+2) is not discriminable from one which is coded (-2) while it is discriminable from one equal to (-1).

Counting model A is defined by the assumption that all intervals other than those which are coded (0) carry full order information. If it is assumed for purposes of illustration that x = .2M, then the standard pair on each trial, which has an interval of zero, will be coded .2(-1) and .8(0), i.e., it will be coded (-1) 20% of the time and (0) 80% of the time. If it is assumed that the subject picks as successive (+1) when he is confronted with a choice between (+1) and (-1), which is optimal because the standard is sometimes (-1) but never (+1), then the successiveness function should look like that in the upper part of Figure 3.

Counting model B assumes that information regarding order is transmitted only when the count is 2 or more in either direction. In this model the subject simply picks the largest count as successive and when he is given a choice between (+1) and (-1), he is correct only half the time. Model B yields the function shown in the lower part of Figure 3. Note that the slope of the rapidly ascending segment on the right for model B is unaffected by the value of x. That is, if x is small, a line which is fitted to data points which are within this segment would give an unbiased estimate of M.

Plan of experiments.- Two major experiments are reported in the following sections. These were undertaken to determine (1) the over-all form of the successiveness discrimination function; (2) the influence of channel uncertainty upon the function; and (3) the effect of varying the interval between the signals of the standard pair. Experiment 1 deals with the first two of these and Experiment 2 with the third.

The expected form of the successiveness function which is predicted by the attention theory can be specified no more exactly than it is in Figures 1 and 2. In the ideal case it would look like Figure 1. For this to occur, two major and unrealistic conditions would have to be met by the subjects. They would have to attend to the visual channel at the moment of the first signal in every pair (i.e., $P_\ell = 1$) and they would

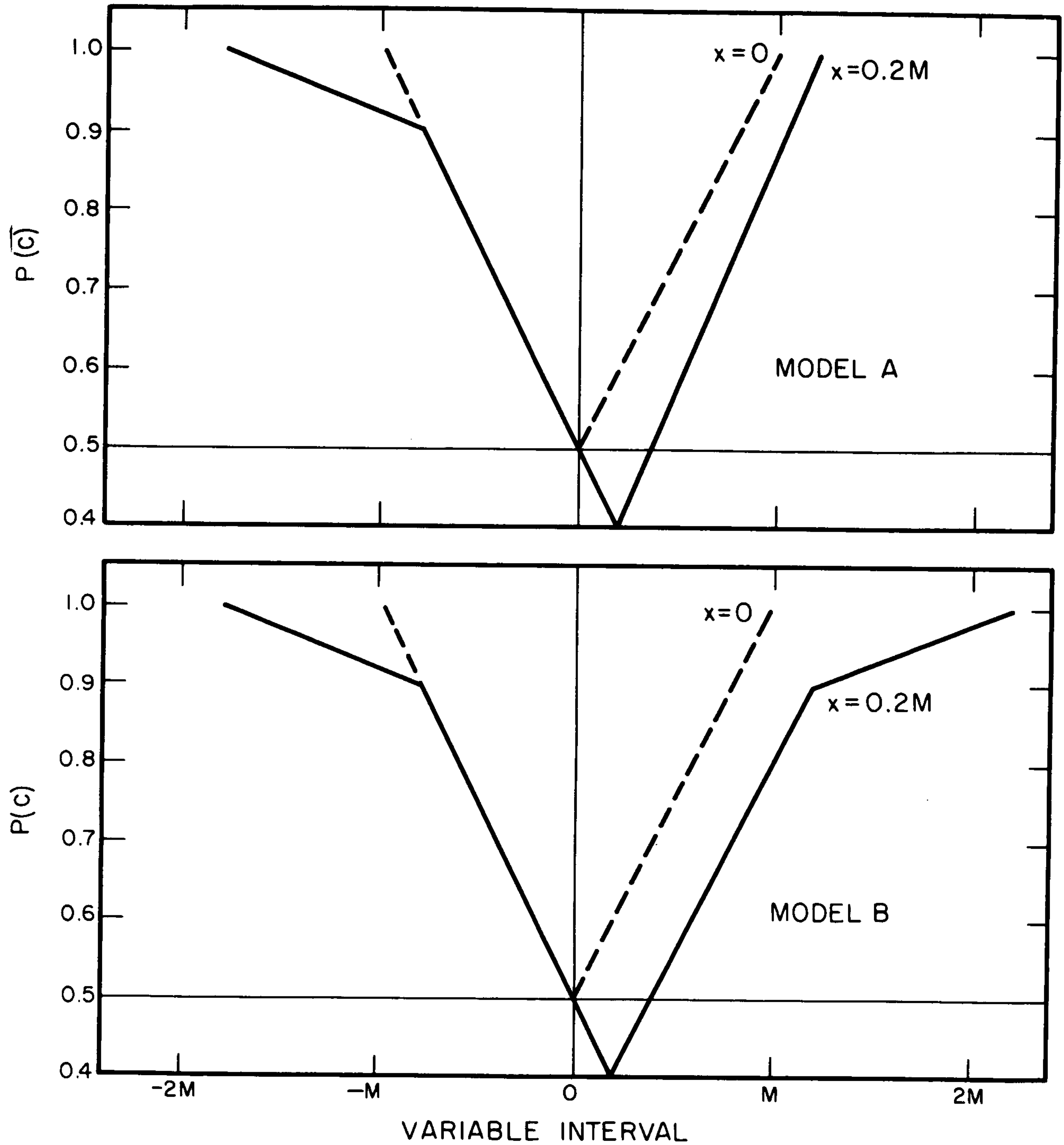


FIG. 3 SUCCESSIVENESS DISCRIMINATION FUNCTIONS PREDICTED BY TWO COUNTING MODELS.

have to switch without fail between channels at every appropriate time point. Furthermore, they would have to do the latter at each of two successive points whenever a negative variable is presented.

If these stringent assumptions are satisfied, then the obtained successiveness functions would consist of three linear segments spanning equal distances on the abscissa as in Figure 1. The total time difference between y, the time which must separate the signals when the light occurs first for 100% discrimination from a standard of zero, and y(-), the corresponding time separation when the sound occurs first, should be equal to 3M.

The most salient way in which the counting models of Figure 3 differ from the attention model is in the center of the function. If x is positive, then the left-hand function rises steeply from the (0,50) origin.

The influence of channel uncertainty, that is, not knowing in advance which signal will occur first, should lead to changes in parts of the function which follow the pattern of Figure 2, according to the attention theory. The idea here is that it should be possible to change P_ℓ by changing the composition of the trials which are presented in a single session. If all positive variables are presented, P_ℓ might be large, if all of the variables are negative P_ℓ might be small and if the condition is one of uncertainty, i.e., both negative and positive variables being presented with no cue as to which is coming next, P_ℓ might take an intermediate value.

The counting models in their present form do not incorporate concepts which can be coordinated to channel uncertainty.

The effect of varying the standard interval is rather clearly predicted by both theories and their predictions differ. According to the attention theory, variations in the standard should be without effect upon the function as long as the standard interval remains in the x to x(-) range. Outside this range an effect is expected and it can be calculated. The counting models on the other hand, predict that any change in the standard should influence the function. The exact forms of these predictions will be presented later.

Method.- The apparatus has been described in (1). The procedures are similar to those described in that report and will be only summarized here.

Two-choice forced-choice data were obtained for each of eight different subjects. All eight took part in Experiment 1. Five of the eight participated in Experiment 2. On each trial two light-sound pairs were presented successively, a standard pair and a variable pair. The standard was presented first on half the trials and second on half. For every pair the light and sound came on together, remained on for two seconds and then terminated. The interval between the two offsets, which offset occurred first, and the relation between these for the standard and the variable were the main variables and will be discussed specifically later for each experiment. In general, the subject was instructed to indicate which pair, the first or the second, he thought was the variable. For a given set of conditions, P(C) was calculated as the proportion of trials on which he did this successfully.

One trial was initiated every 15 seconds and two seconds elapsed between the first and second pairs. This provided enough time following the second pair for the subject to make his decision and to register his response, which he did by pressing one of two keys. If the response was correct, he was so informed.

One day's session consisted of 84 trials, divided into two runs of 42 by a short break. Practice sessions were given before final data were collected. The number of practice days varied substantially among subjects but the final sessions were not begun for an individual until his performance appeared to stabilize.

Experiment 1
The Effect of Uncertainty upon Successiveness Discrimination Functions

This experiment was performed to determine some of the characteristics of successiveness discrimination functions and to assess effects of channel uncertainty upon the functions. It consists of two parts, the results of which will be presented separately followed by a discussion of both.

Part A.- In previous experiments (2) data had been obtained under the certainty condition, using only positive values of the variable interval, for each of the four subjects who participated in this part. These earlier data provide a baseline against which to compare their performance under uncertainty.

As in the previous experiments, a standard with an interval of zero was used here. A number of values of the variable interval were used, some of them positive and some negative. The various values were randomly intermixed over trials and the subject was not informed prior to each trial of either the value of the variable or whether it would be positive or negative. He was instructed to indicate the successive pair on each trial.

The number of presentations of each value of the variable and the number of correct responses for each are tabled in Appendix A for the individual subjects. Figures 4 and 5 show the results in terms of P(C).

A line was fitted to the data points in the right half of each graph using the least-squared error procedure described previously (2). This line is the solid line in the right half of each graph in Figures 4 and 5. The dashed line in each graph is the line obtained earlier for each subject under the certainty condition.

The differences between the solid and the dashed lines are trivial for three of the subjects. The fourth, JC, shows a small change in x of about 7 msec. but no change in slope. In general, it can be said that uncertainty exerted no appreciable effect upon the positive segment of the function in this experiment.

Since the subjects show no change as a result of uncertainty, it is necessary to conclude that P_ℓ is unchanged by the change

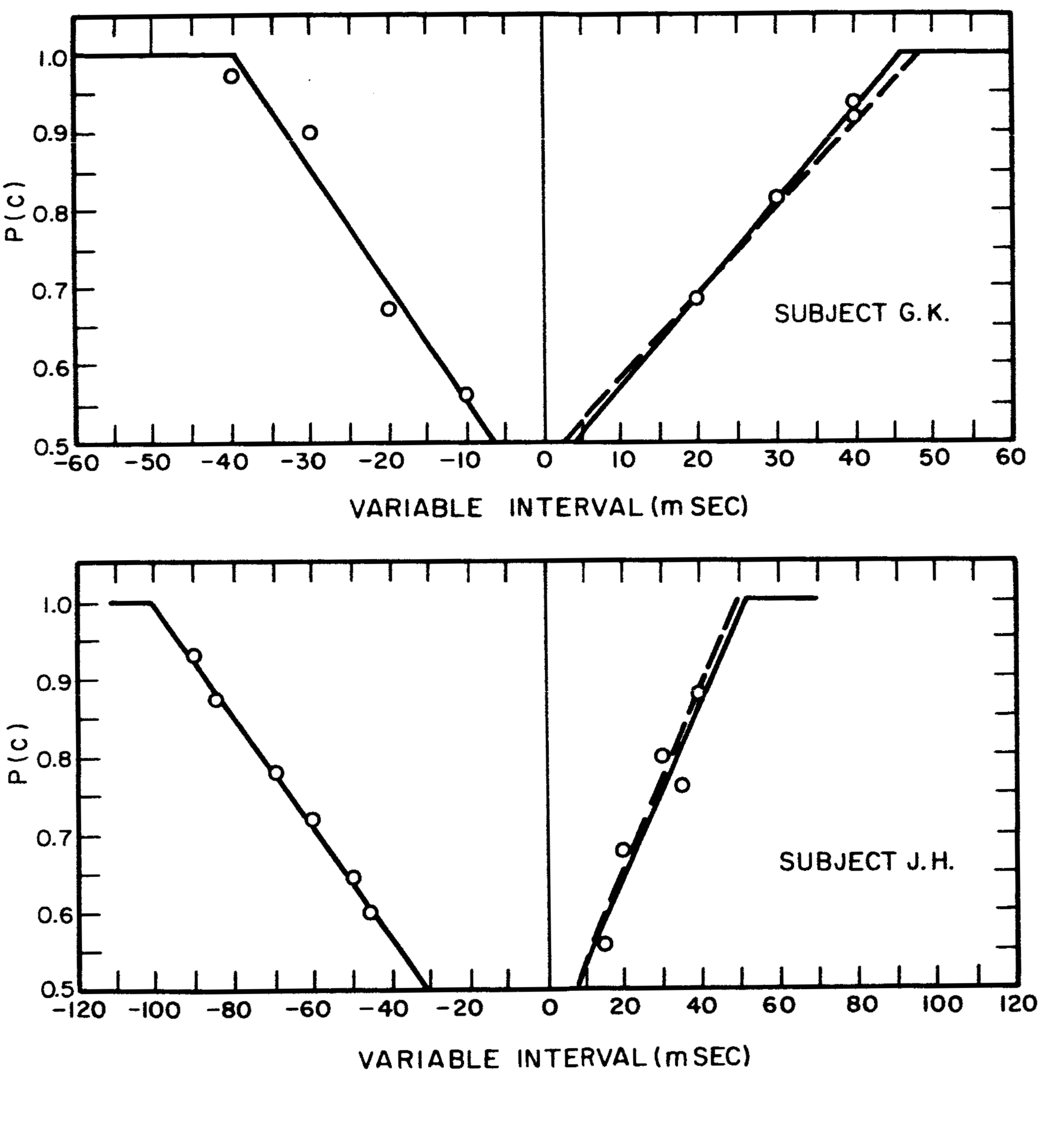


FIG. 4 SUCCESSIVENESS DISCRIMINATION FUNCTIONS OBTAINED UNDER UNCERTAINTY. THE DASHED LINES ARE THE RESULTS OBTAINED EARLIER UNDER CERTAINTY FOR POSITIVE VALUES OF THE VARIABLE INTERVAL.

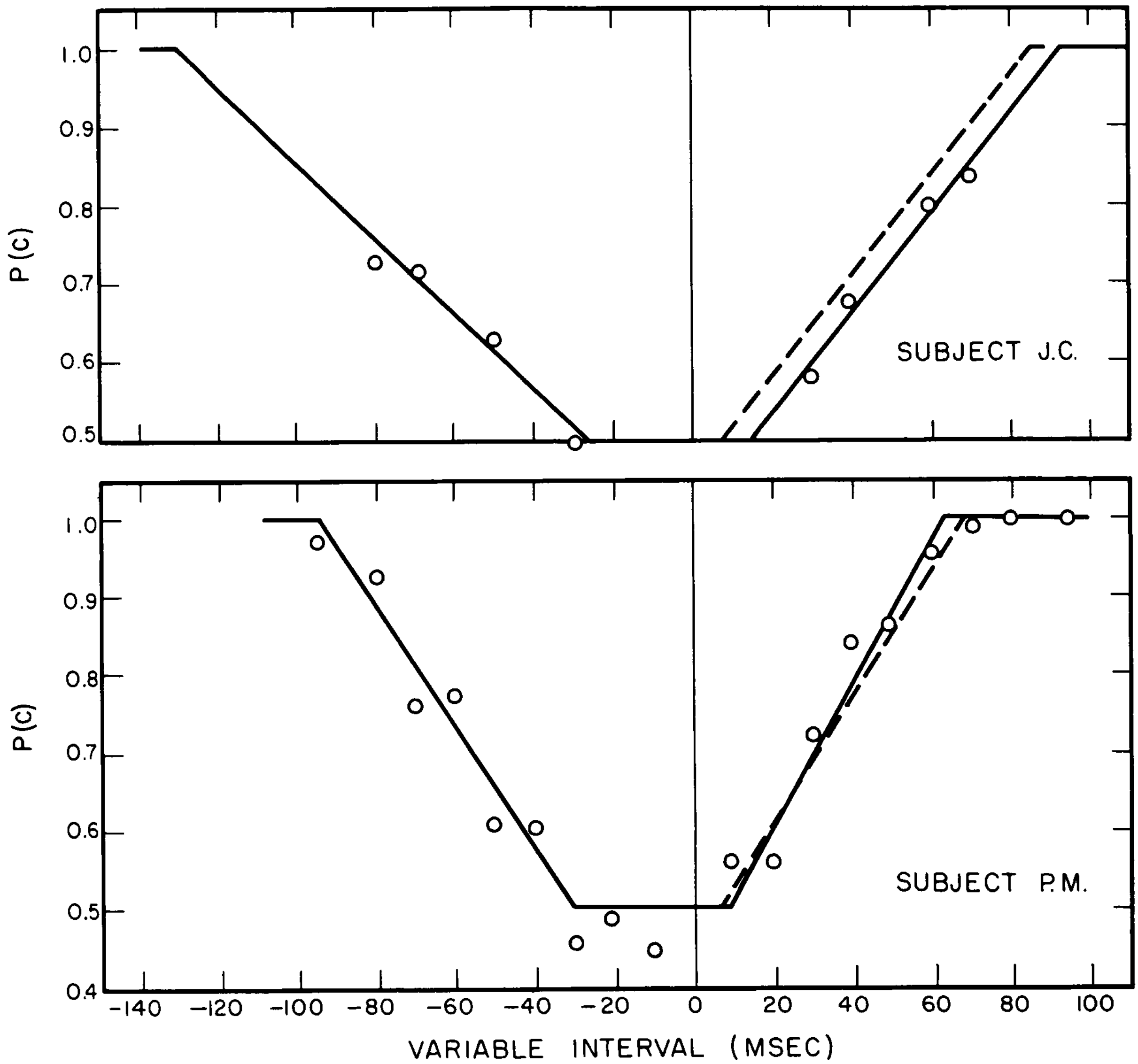


FIG. 5 SUCCESSIVENESS DISCRIMINATION FUNCTIONS UNDER UNCERTAINTY. THE DASHED LINES ARE THE RESULTS OBTAINED EARLIER UNDER CERTAINTY FOR POSITIVE VALUES OF THE VARIABLE INTERVAL.

in procedure. Fitting a single line to the data is justified only if P_ℓ is close to unity and this assumption, that $P_\ell = 1$, is as well satisfied by the present uncertainty data as it was by the earlier data.

Continuing the analysis within the context of attention theory, if P_ℓ is very nearly one under uncertainty, then the data in the left half of each graph should also be linear (see Figure 1) and a second-line segment is shown on the negative side of each graph which is the line of best-fit to the points on that side.

The complete functions can then be described by a set of four points along the abscissa: those points at which the two ascending segments reach a P(C) of 1.0 which are called y on the positive side and y(-) on the negative side, and the two points of intersection with the P(C) = .5 line which are called x and x(-). These values are given in Table I along with x and y for the certainty functions.

The average of y is 63.3 msec. under uncertainty and 62.8 under certainty. For x, the corresponding mean values are 8.7 and 5.9. These means demonstrate again the lack of effect exerted by uncertainty upon the positive limb of the function in this experiment.

Part B.- All of the subjects in Part A had extensive experience with the successiveness task prior to their participation in Part A and all of the prior experience had consisted of sessions in which conditions were arranged to maximize P_ℓ.

All of the hundreds of signal pairs which they had observed were either simultaneous pairs or pairs in which the visual signal occurred before the auditory signal.

The results of Part A indicate that the subjects behaved under uncertainty in the same way as they had behaved previously under certainty. This finding is open to a number of rather obvious interpretations at this point. One possibility is that changes in P_ℓ do not have the effects upon the discrimination function which are predicted by the attention theory. Another possibility is that an observing set, i.e., a high value of P_ℓ, was so thoroughly built in as a result of the prior experience

TABLE I

VALUES OF THE VARIABLE INTERVAL AT WHICH THE LINES OF BEST-FIT PASS THROUGH P(C) = .50 [x(-) and x] AND THROUGH P(C) = 1.0 [y(-) and y] FOR THE UNCERTAINTY CONDITION OF EXPERIMENT 1A. ALSO INCLUDED ARE x AND y OBTAINED UNDER CERTAINTY.

Subject	Uncertainty				Certainty	
	y(-)	x(-)	x	y	x	y
GK	40.1	6.3	4.1	45.9	1.9	48.1
JH	101.9	29.7	7.0	52.1	7.5	49.7
PM	94.1	31.2	9.2	62.7	6.7	69.4
JC	131.4	26.4	14.6	92.5	7.3	84.0

that it simply carried over unaltered throughout Part A; there was no compelling reason to change the set. A third possibility is that P_{ℓ} is high in this kind of observing situation and that it is not readily changed. That is, it is conceivable that there is a natural bias which strongly favors attending to the visual channel when two events, one visual and one auditory, are expected to happen at about the same time.

This part of Experiment 1 was designed to provide additional information on the complete successiveness function and to try to discriminate among some of the possible interpretations of the results of Part A.

Four new subjects were selected, none of whom had had previous experience with successiveness discrimination. All four, however, had taken part in a series of reaction time experiments using the same signals in the same environment as reported previously (3).

Three experimental conditions were applied to each subject:

a. Positive variable intervals only: certainty.

b. Negative variable intervals only: certainty.

c. Both positive and negative intervals: uncertainty.

The four subjects were divided into pairs and a different order of the conditions was administered to each pair according to the following schedule in which the letters designate the conditions listed above:

Session Number	Subjects	
	KQ and DC	NG and NC
1 - 12	a	b
13 - 23	c	c
24 - 29	b	a
30 - 37	c	c
38 - 42	a	b

Following session 42, eight more sessions were conducted for each subject in which only one positive and one negative variable interval were used. Half of these were under conditions of certainty and half were under uncertainty. Finally, ten sessions were devoted to obtaining additional single values of P(C) under the certainty condition. A total of 60 sessions was conducted for each of the four subjects.

In Part A only the positive half of the successiveness function was obtained for the certainty condition. In Part B complete functions were measured for both certainty and uncertainty.

The raw data for Part B are given in Appendix B. Figures 6 - 9 show the successiveness functions for certainty and for uncertainty for each subject. As before, a line was fitted to each set of points. The dashed lines in the lower half of each figure are the same as the lines from the upper half; they are drawn in to facilitate comparison.

Table II summarizes the points of intersection of the lines with P(C) = .5 and P(C) = 1.0 in the same manner as in Table I of Part A.

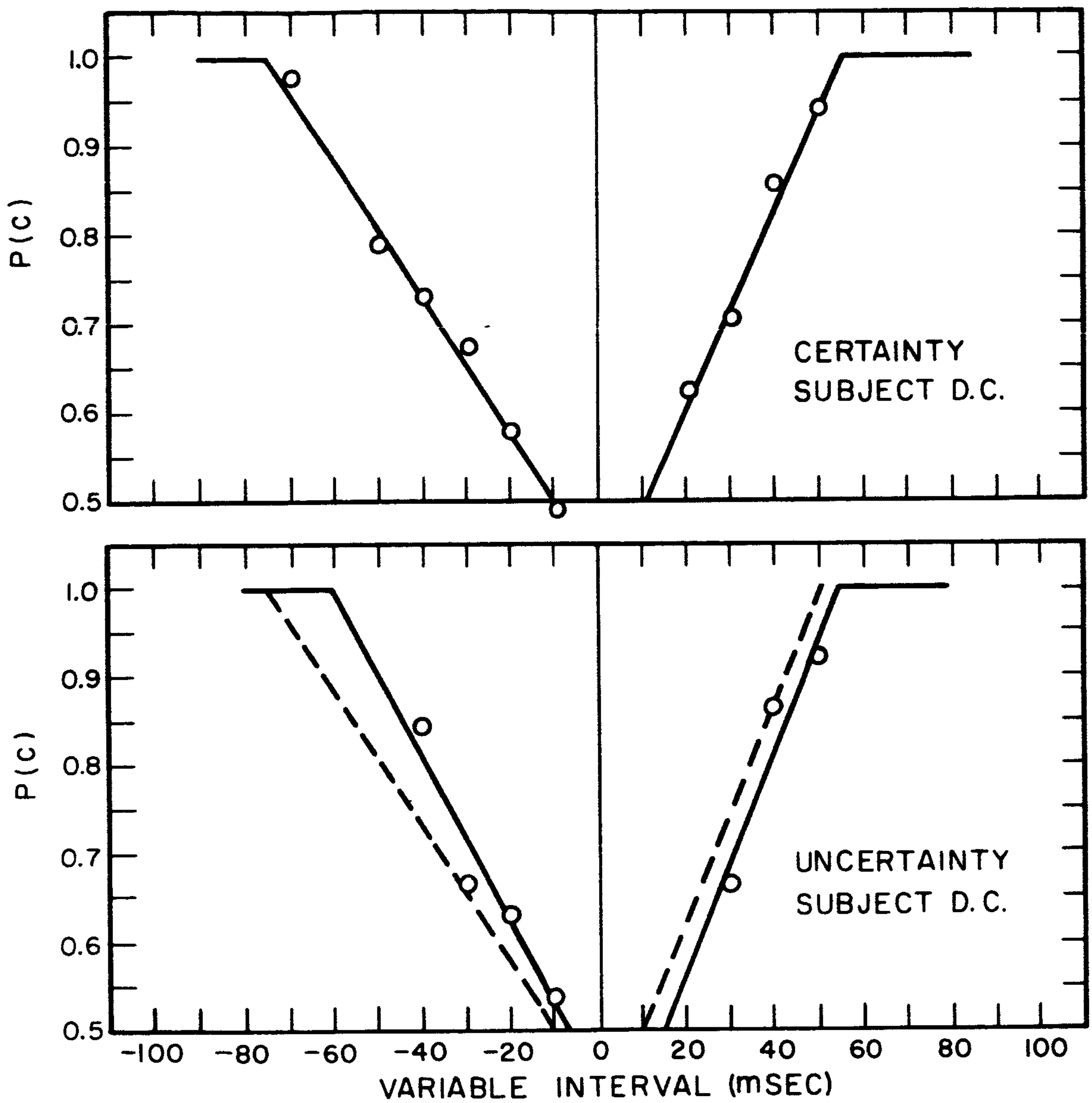


FIG. 6 SUCCESSIVENESS DISCRIMINATION FUNCTIONS UNDER CERTAINTY AND UNDER UNCERTAINTY. THE DASHED LINES ARE THE SAME AS THE SOLID LINES OF THE UPPER GRAPH.

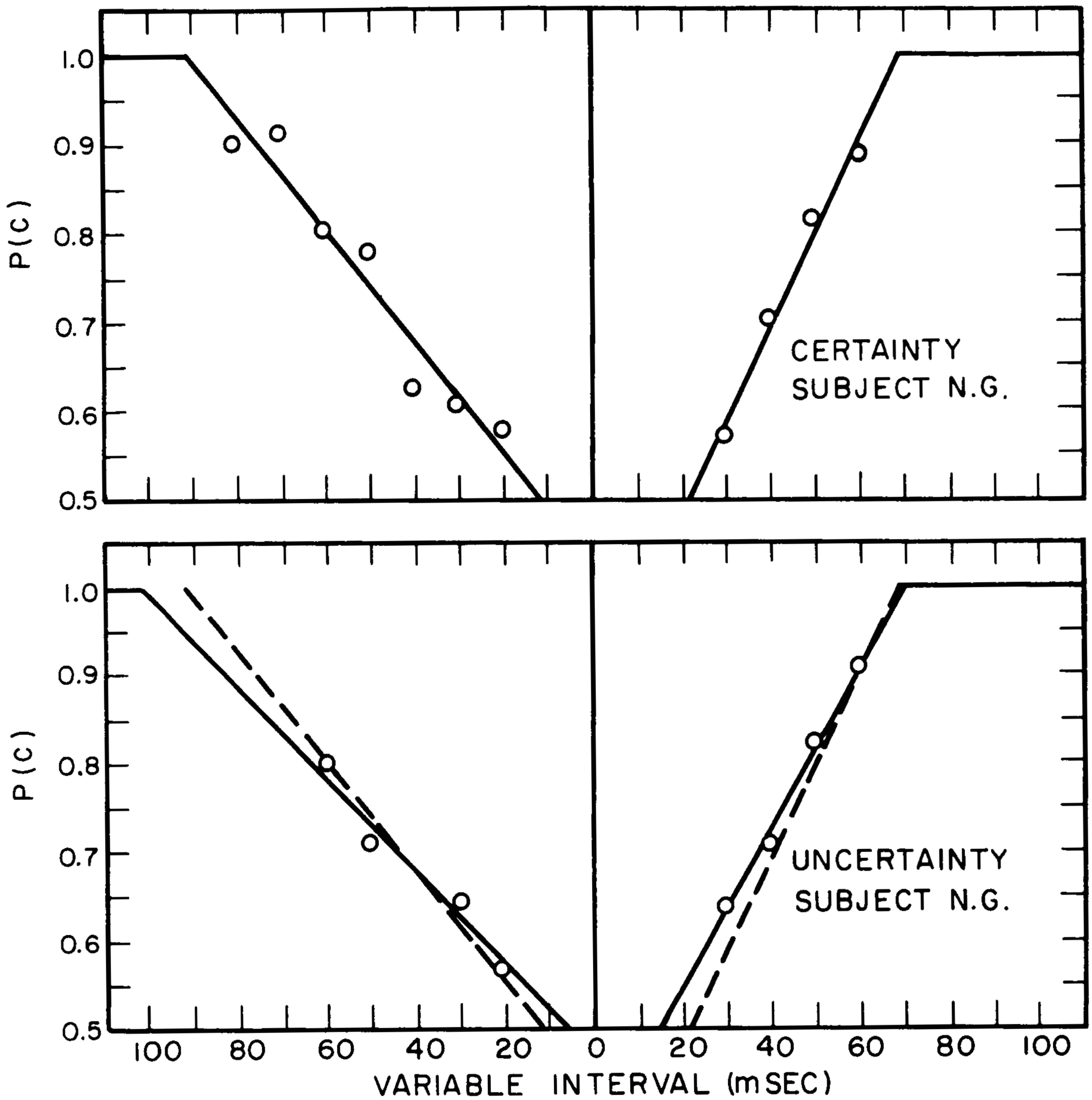


FIG. 7 SUCCESSIVENESS DISCRIMINATION FUNCTIONS UNDER CERTAINTY AND UNDER UNCERTAINTY. THE DASHED LINES ARE THE SAME AS THE SOLID LINES OF THE UPPER GRAPH.

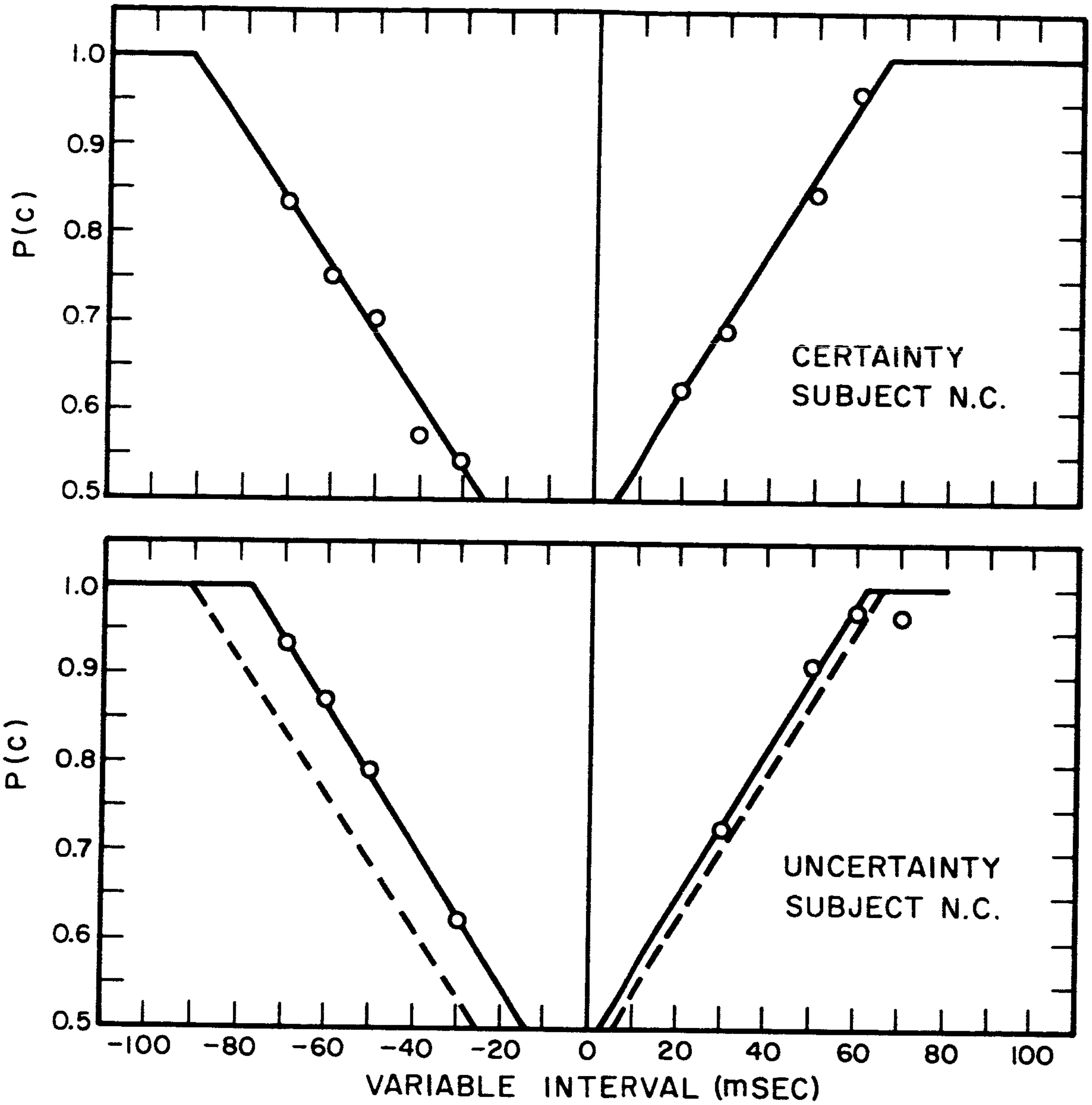


FIG. 8 SUCCESSIVENESS DISCRIMINATION FUNCTIONS UNDER CERTAINTY AND UNDER UNCERTAINTY. THE DASHED LINES ARE THE SAME AS THE SOLID LINES OF THE UPPER GRAPH.

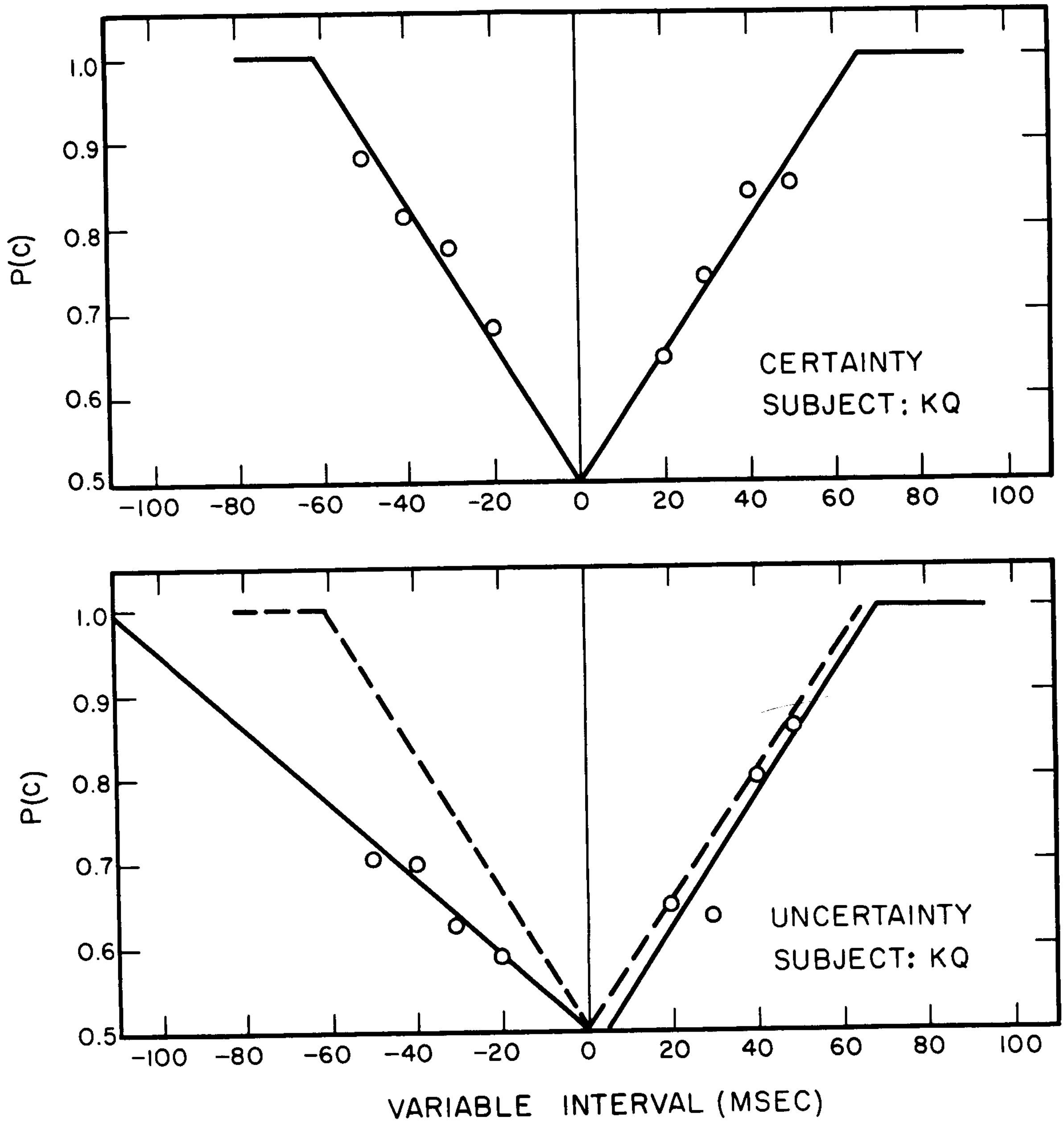


FIG. 9 SUCCESSIVENESS DISCRIMINATION FUNCTIONS UNDER CERTAINTY AND UNDER UNCERTAINTY. THE DASHED LINES ARE THE SAME AS THE SOLID LINES OF THE UPPER GRAPH.

TABLE II

VALUES OF THE VARIABLE INTERVAL
AT WHICH THE LINES OF BEST-FIT PASS THROUGH
P(C) = .5 [x(-) and x] AND P(C) = 1.0 [y(-) and y]
FOR THE TWO CONDITIONS OF EXPERIMENT 1B.

Subject	Uncertainty				Certainty			
	y(-)	x(-)	x	y	y(-)	x(-)	x	y
DC	59.8	7.3	15.7	54.5	74.1	10.5	11.8	51.2
NC	77.1	14.4	2.7	62.1	91.5	26.7	5.6	66.9
NG	101.8	5.4	15.6	70.5	91.4	11.6	22.3	69.5
KQ	111.6	0	4.5	68.5	62.0	0	0	64.9

Discussion of results.- The lack of effect of uncertainty upon the positive limb of the discrimination function which was noted in Part A was observed also in Part B. The data relevant to this comparison are presented in Table III for all eight subjects in terms of the parameters x and M. It is quite clear that uncertainty has a negligible effect upon both parameters.

These data can be used to estimate the error involved in measuring M. The mean absolute difference in M, over individuals, between the two measurements is only 3.6 msec. with a standard deviation of 3.0. On the average, therefore, a second measurement of M will be within 3 or 4 msec. of a first measurement when each measurement is based upon the moderate number of responses obtained in each case in this study. The mean and standard deviation of the absolute differences in x are 3.8 and 2.2, respectively.

These measurements also reliably differentiate among individuals, in spite of the rather narrow range of individual differences. The rank-order correlation coefficients calculated from Table III are .81 for x and .90 for M.

TABLE III

EFFECT OF UNCERTAINTY UPON THE PARAMETERS x AND M
AS DETERMINED FROM THE
POSITIVE LIMB OF THE DISCRIMINATION FUNCTIONS

Subject	x		M	
	Certainty	Uncertainty	Certainty	Uncertainty
GK	1.9	4.1	46.2	41.8
JH	7.5	7.0	42.2	45.1
PM	6.7	9.2	62.7	53.5
JC	7.3	14.6	76.7	77.9
KQ	0	4.5	64.9	64.0
DC	11.8	15.7	39.4	38.8
NC	5.6	2.7	61.3	59.4
NG	22.3	15.6	47.2	54.9
Mean	7.9	9.2	55.1	54.4

The data of Table III are consistent with the conclusion that $P_{\bar{\ell}}$ is unchanged by uncertainty. Since this seems to be as true for the two subjects (NC and NG) who had prior experience with only negative variable intervals as it is for the others, it would appear that the result cannot be attributed to the prior development of an observing set, although there is not enough data here to allow one to state this conclusion with confidence.

The negative limb of the successiveness function differs from the positive limb. For one thing, the range of values of slope is much larger for the negative limb as can be seen in Table IV. The total span of the negative limb, M(-), has a range of 78 msec. while the range for M is 39. Also, M(-) is larger than M to a significant extent (75 vs. 54 for the group)

TABLE IV

VALUES OF M AND M(-) OBTAINED UNDER UNCERTAINTY

Subject	M(-)	M
GK	33.8	41.8
JH	72.2	45.1
PM	62.9	53.5
JC	104.6	77.9
KQ	111.6	64.0
DC	52.5	38.8
NC	62.7	59.4
NG	96.4	54.9
Mean	74.6	54.4

and this is true for seven of the eight subjects. Nonetheless, M and M(-) are significantly correlated over individuals (rho = .66).

Whether uncertainty affects the negative limb can be determined for only the four subjects of Part B. This comparison is shown in Table V. Uncertainty increased M(-) by 50 msec. for subject KQ but had little or no effect for the other three subjects who average 69 msec. for certainty and 70 msec. for uncertainty.

TABLE V

THE EFFECT OF UNCERTAINTY UPON M(-)

Subject	M(-)	
	Certainty	Uncertainty
KQ	62.0	111.6
DC	63.6	52.5
NC	64.8	62.7
NG	79.8	96.4

There are other ways in which KQ seems to differ qualitatively from the others. These will be brought out later. For the present, note should be taken of the lack of effect of uncertainty for the other three subjects. This is particularly important because it implies that P_ℓ remains very high even when only negative variable intervals are presented and when the subject knows in advance that such will be the case. To continue to entertain the expectations of the attention theory in the face of this result is most difficult. It implies that attention is locked on to the visual channel in this observing situation even under conditions in which it would be highly advantageous to attend to the auditory channel instead. This might be true, of course, but it does seem unlikely.

Next to be considered is the question of the over-all form of the successiveness function. Complete data are available for all subjects for the uncertainty condition and a review of Figures 4 - 9 reveals that six individuals manifest the flat center segment which was shown in Figure 1 to be expected by the attention theory when $P_\ell = 1$. One subject, KQ, definitely does not: both the positive and negative limbs of his function pass very nearly through zero when P(C) = .5, more in accord with the expectations of the counting models. The eighth subject, GK, is equivocal, x being 4 and x(-) being 6 for him. The six subjects who seem to form a homogeneous group in this respect are summarized in Table VI and an average function, based upon the lines which were fitted to their data under the linear hypothesis of the attention theory, is shown in Figure 10.

The successiveness function which is derived from attention theory for $P_\ell = 1$ is shown in Figure 10 by the dashed lines. This construction assumes an M of 50 and is drawn arbitrarily through the obtained y of 65.7. The assumed value of M was selected to be slightly too small to make the comparison somewhat clearer. It is apparent in Figure 10 that if the theoretical M were assumed to be 53 instead of 50, then the theoretical and obtained lines on

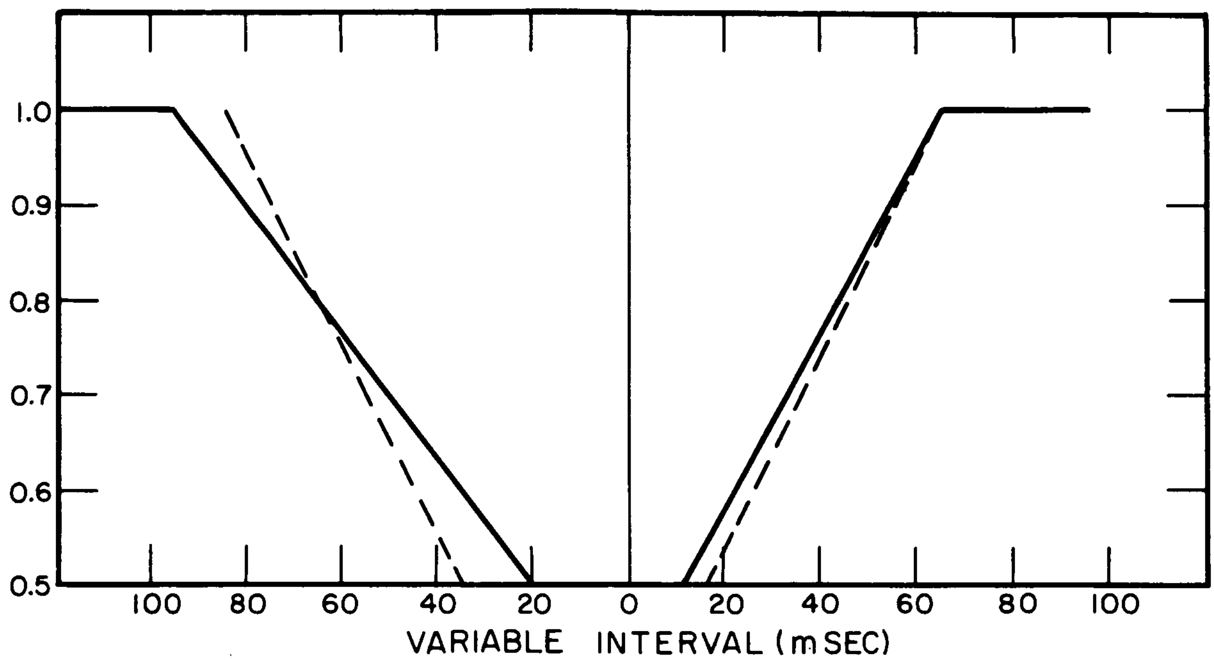


FIG. 10 THE SOLID LINES ARE THE AVERAGE SUCCESSIVENESS DISCRIMINATION FUNCTION FOR THE GROUP DEFINED IN THE TEXT. THE DASHED LINES ARE EXPECTED FUNCTION BASED ON ATTENTION THEORY, ASSUMING M = 50

the right would agree almost perfectly and also the theoretical value of y(-), the P(C) = 1 intercept on the left, would be shifted 9 msec. to the left and would agree with the obtained value of y(-) within one msec.

One major discrepancy would remain and would be enhanced by the slight increase in the assumed M: the obtained value of x(-) is much smaller than predicted.

TABLE VI

VALUES OF y(-), x(-), x AND y DERIVED FROM THE UNCERTAINTY DATA FOR SIX SUBJECTS WHO ARE INCONSISTENT WITH THE COUNTING MODELS

Subject	y(-)	x(-)	x	y
JH	101.9	29.7	7.0	52.1
PM	94.1	31.2	9.2	62.7
JC	131.4	26.4	14.6	92.5
DC	59.8	7.3	15.7	54.5
NC	77.1	14.4	2.7	62.1
NG	101.8	5.4	15.6	70.5
Mean	94.4	19.1	10.8	65.7

Therefore, the obtained successiveness function is adequately described by three linear segments which together span three times the distance spanned by the positive ascending segment. That is, if M is the span of the positive segment, then the total function spans 3M. These relationships are exactly those predicted by attention theory. However, the three obtained segments do not span equal distances on the abscissa; the left segment is larger and the middle segment is smaller than predicted. If P_ℓ were slightly less than unity, a discrepancy of this kind would be expected to occur (see Figure 2). However, to make a case for such an interpretation, one would have to have many more data points for each subject than are available now.

Summary of results.- The following are the major results of this experiment:

1. The major parameter M can be measured with satisfactory reliability. A second measurement of M will be within 4 msec., on the average of the first, when it is obtained from the positive limb of the successiveness function using procedures like those of this experiment. This measurement error is small enough to allow individual differences to be reliably reproduced, the correlation over individuals being about .90.

2. Knowledge as to which signal will occur first is virtually without affect upon the successiveness function. In twelve instances, an effect was obtained only once and in that case uncertainty lengthened M by 50 msec.

3. Neither theoretical model is an adequate description of the successiveness function for all eight individuals. Six subjects resemble the model of attention theory, one the counting model and one is equivocal. The six are congruent with the simplest model of attention theory in all ways save one.

The subject who showed the one effect of uncertainty was the one subject whose data conformed to the form expected by the counting theory.

Experiment 2

The Effect of Variation in the Standard Interval Upon Forced-Choice Successiveness Discrimination

Measurements of the parameter M have depended for their validity upon an assumption about the effect of the interval of the standard upon the forced-choice judgement. If the standard interval is exactly equal to x, then a single linear function with a span of M is expected by both of the theories discussed in the introduction. However, since x can only be estimated, it is not possible to set the standard interval exactly equal to it. The attention theory suggests that this may not be a critical factor because all intervals in the range between x and x(-) are equivalent to an interval of x, providing $P_{\ell} = 1$.

This experiment was designed to test this deduction by determining the effect upon P(C) for a single value of the variable interval of changes in the standard interval, both within and outside of the x to x(-) range. The three theoretical models which were discussed in the introduction lead to very different predictions concerning this effect as illustrated in Figure 11.

The example shown in the figure assumes that x = .2M and that a positive variable interval, V, equal to .8M is chosen for

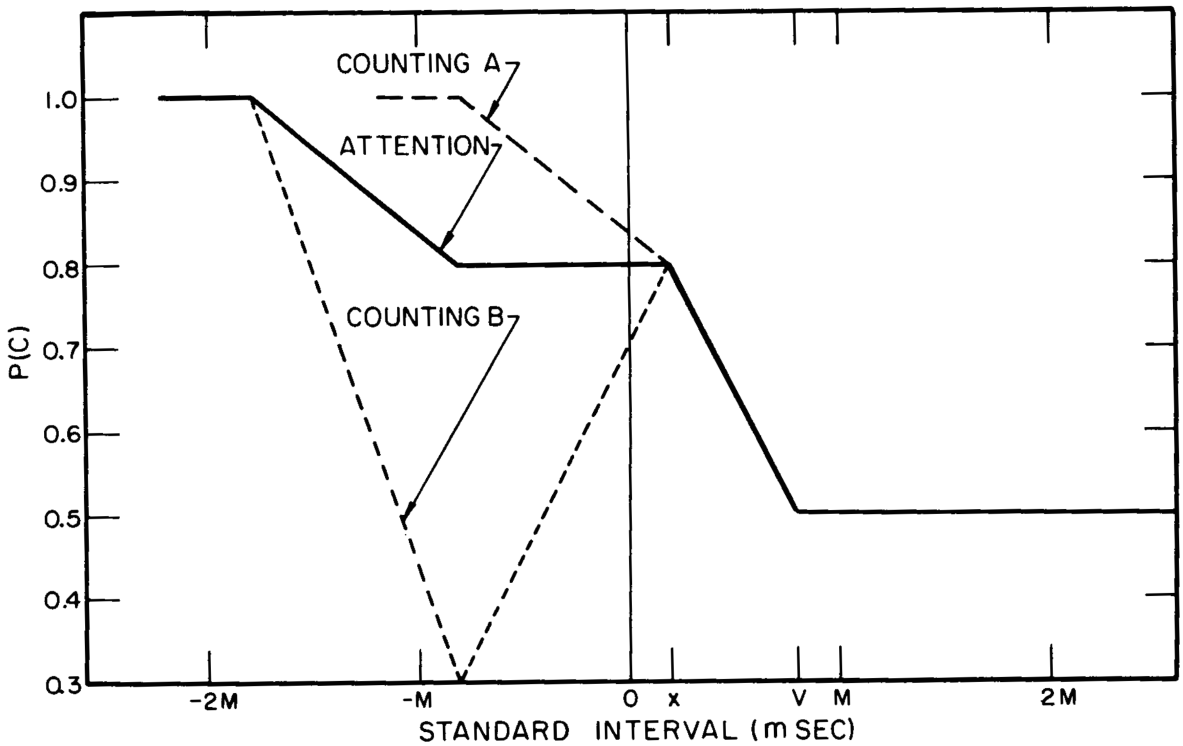


FIG. 11 THE EFFECT OF VARYING THE INTERVAL OF THE STANDARD UPON P(c) FOR A VARIABLE WITH AN INTERVAL OF 0.8 M AS PREDICTED BY EACH OF THREE MODELS. x = 0.2 M

study. Under these assumptions a standard interval equal to x should yield a P(C) of .80 according to all three models and P(C) should approach .5 linearly as the standard interval increases from x to V in value. This region of the function does not differentiate among the models because in this region both the standard and the variable are coded as either (0) or (+1) on all trials and all three models assert that (+1) can be distinguished without fail from (0).

For standard intervals in the range which covers one M immediately below x, the three models differ greatly. In this range, the standard interval is always coded either (0) or (-1) while the variable, of course, is still coded either (0) or (+1). Since the attention model leads to the deduction that (-1) is equivalent to (0) (since two switching points are required when an interval is negative), the function should be flat in this region as indicated by the solid line in Figure 11. Counting model A assumes that (-1) and (0) are fully distinguishable; hence when the standard interval equals (x - M) and is always coded (-1), then P(C) for the variable must be 1.0. This is indicated by the dashed line at the top of the figure.

Counting model B assumes that (-1) differs from (0) but that it is equivalent to (+1) since order information is assumed not to be utilizable unless there are at least two intervening points. Thus, for a standard interval of (x - M), P(C) is reduced to .30, a level substantially below chance.

Finally, in the range covering one M immediately below (x - M), the two lower functions ascend linearly to 1.0 as the proportion of trials on which the standard is coded (-2) increases to 1.0.

Procedure.- The results of this experiment will be presented in two parts. In Part A an attempt was made to determine a function like Figure 11 in detail for a single experimental subject. Part B consists of a less-complete determination of the function for each of four additional subjects.

The same general procedure was followed in both parts. From the data of Experiment 1, a value of the variable interval which produced a P(C) of about .8 was selected for each subject. In each session one non-zero value of the standard interval was paired with the variable and the proportion of trials on which the variable was chosen by the subject was determined.

Intermixed with these trials in a random manner were trials on which a standard interval of zero was used with the same variable. This was done to provide a continual assessment of baseline performance over the long series of sessions.

Thus, the variable was presented on every trial together with a standard of either zero or the single non-zero value selected for that session. Ordinarily, at least three sessions of eighty trials were performed with one value of the non-zero standard before a new value was selected. With only a couple of exceptions, the number of trials with the zero standard was the same as the number with the non-zero standard.

In all other respects the procedure was the same two-choice forced-choice procedure used in previous experiments.

Results - Part A.- Subject JH, who had participated in Part A of Experiment 1, continued in this part of Experiment 2. More than 80 experimental sessions were conducted using 18 different values of the non-zero standard. In several of the sessions, only standards of zero were presented. The raw data are summarized in Appendix C in terms of the number of trials and the number of correct responses for each non-zero standard and for the zero standard which accompanied it. Most of the data points are based on 100 responses although as many as 500 were obtained for certain critical points.

The variable interval was +30 msec. In Experiment 1, the values of x and M which were obtained for JH under the certainty condition were 5 and 42.2 msec., respectively. From these two values, P(C) for a standard of zero would be expected to be .796 for the selected variable. A measured value of .798 was obtained in the present experiment during those sessions in which no non-zero standard was presented.

As can be seen in the lower part of Figure 12, P(C) for the standard of zero was slightly and consistently depressed during those sessions in which a non-zero standard was also presented. The extent of this depression is somewhat greater for the larger negative non-zero standards.

The function relating P(C) for the +30 variable to the standard interval is shown in the upper part of Figure 12. The linear

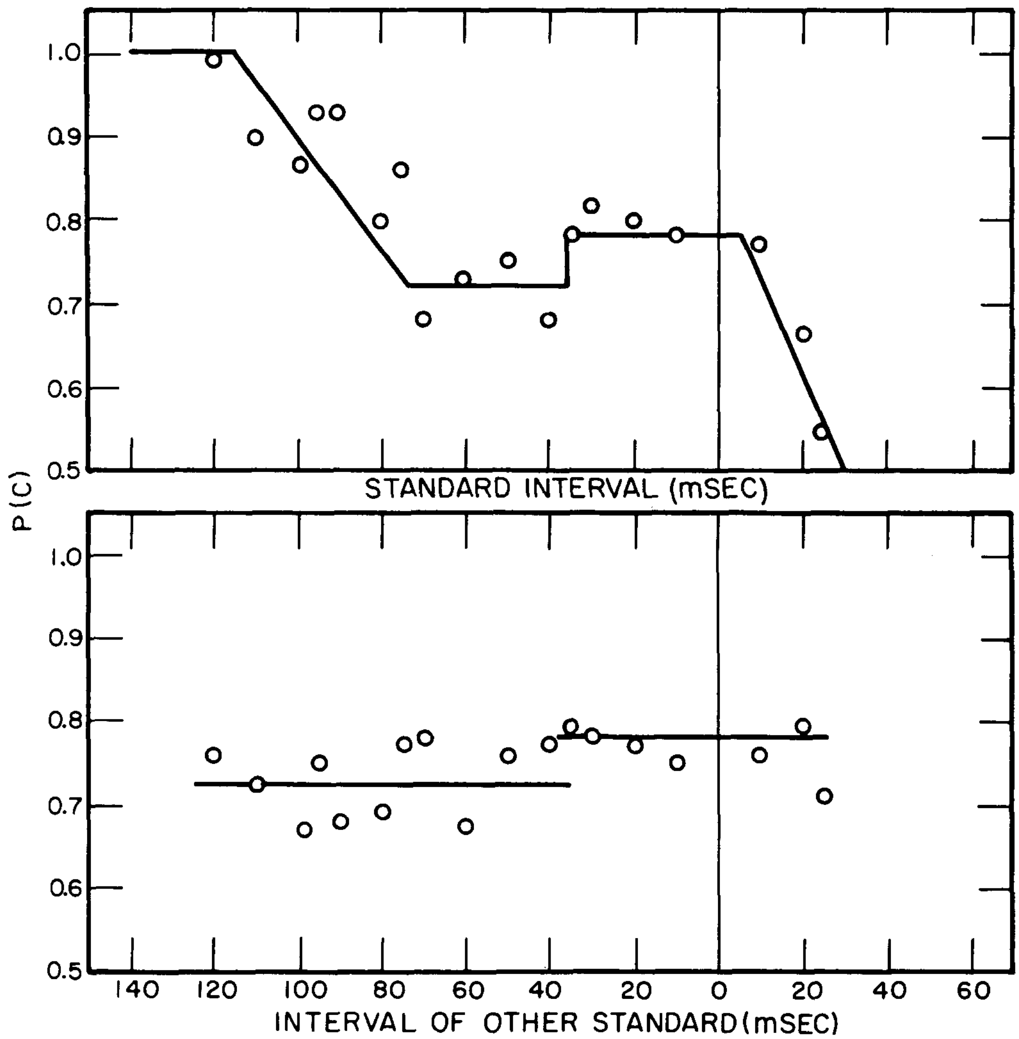


FIG. 12 UPPER. OBTAINED DATA AND FUNCTION PREDICTED FROM PARAMETERS MEASURED IN EXPERIMENT 1 AS EXPLAINED IN TEXT.

LOWER. EFFECT ON P(c) FOR A STANDARD OF ZERO OF THE PRESENCE WITHIN A SESSION OF A STANDARD HAVING THE VALUE INDICATED ON THE ABSCISSA. VARIABLE INTERVAL = +30, SUBJECT J.H.

segments which make up the predicted function in this figure are based upon the parameters measured in Experiment 1.

There is one major and perfectly clear discrepancy between these data and all three of the theoretical functions of Figure 11. In order to discriminate a variable of 30 from a negative standard with a probability of one, the negative standard must be at least three M-units below x, rather than the two units shown in Figure 11.

As the standrad interval becomes increasingly negative, beginning at x, there is no change in P(C) over the interval down to (x - M). Then P(C) seems to drop to a lower value between (x - M) and (x - 2M). Below (x - 2M) it rises rapidly and reaches unity at about (x - 3M).

The drop in the function over the second quantum below x might be due to a partial inability to discriminate intervals which are coded (-2) from those coded (+1), a view which combines the logical properties of the attention model and counting model B. I have tried to account for it in this manner and have failed to find a compromise model which will reproduce the quantitative aspects of the data.

The drop occurs for those data points below -35. Note in the lower figure that this is approximately where performance on the zero standard is also depressed. Furthermore, the drop in performance is of about the same magnitude in the two figures. If it is assumed that some independent source of error is operating below -35 and if one adjusts the data in the upper figure, using that in the lower figure to estimate the probability of an extraneously-caused error, the result is unsatisfactory because those points in the upper figure which are in the third quantum below x are greatly overcorrected.

The predicted function in the upper figure is based in part upon an assumption which does account for the dip. This assumption is that the value of x is different during those sessions when the non-zero standard is less than -35. The possibility that x may be "adjustable" has arisen in another experiment also (4). If x is assigned a value of 6.4 for standards of -35 and above and a value of 11.3 for those of -40 and below, then one obtains the predicted function shown in upper Figure 12. This assumption also predicts the two levels of performance on the zero standard in the manner represented by the two line segments in lower Figure 12.

If this interpretation of the dip is accepted, then these data suggest that subject JH can discriminate (+1) from (0), (-1), (-2), or (-3), that he cannot discriminate among (0), (-1), and (-2), and that he can discriminate (-3) from all of the other categories.

Results - Part B.- Four more of the subjects who had taken part in Experiment 1 were used to obtain additional data under conditions similar to those reported in the preceding section. Each session consisted of 88 trials, half with a standard of zero and half with one of some non-zero magnitude. Four consecutive sessions were run for each non-zero standard, yielding 176 responses per point for each standard. Nine such pairs of points were determined for three of the subjects and ten for the fourth, enough to sketch the function for each but not enough to determine it in as much detail as in Part A.

From his earlier data, a variable interval having a P(C) of approximately .8 when paired with a standard of zero was selected for each subject. For two subjects a negative interval was chosen (-30 for KQ and -60 for NG) and for two a positive one was used (50 for NC and 40 for DC). This variable interval was used throughout.

The obtained probabilities are tabulated in Appendix D and Table VII shows the over-all P(C) obtained for the zero standard in this experiment and the value which was expected based upon the previous performance of the subject in Experiment 1 under the certainty condition.

TABLE VII

P(C) OBTAINED WITH THE ZERO STANDARD IN PART B
COMPARED TO THE VALUE
OBTAINED IN EXPERIMENT 1 FOR THE SAME VARIABLE

	Subject			
	KQ	NG	NC	DC
Experiment 1	.773	.800	.850	.864
Experiment 2B	.784	.841	.696	.747

The Experiment 1 probabilities were calculated from the line of best fit which was determined by a reasonably large number of responses. Each P(C) for Experiment 2B in Table VII is based upon 1584 trials.

One subject, KQ, performed the same as he had in Experiment 1. The other three showed a change, NG improving slightly and NC and DC demonstrating a marked drop.

Because of these differences in performance from Experiment 1, it is not reasonable to use the parameters measured in Experiment 1 to predict the results of the present experiment as was done in Part A for JH. Instead, a different method of analysis is used to describe the major results.

Figures 13 and 14 present the data which are of primary interest. The points are the obtained data. The lines are functions which were calculated to show up the major feature of each subject's obtained function. These "predicted" functions are all based upon an assumed M of 50 msec. This assumption, together with the P(C) for the zero standard obtained in this experiment and given in Table VII are enough to determine the function which would be predicted by each of the theoretical models.

Even a casual inspection of the obtained functions is sufficient to reveal that no one of the theoretical models is adequate to describe all four subjects. In fact, three different models are demanded. One of the subjects, NC in Figure 14, is similar to JH in that his function is flat over a two-quantum range before it begins to rise toward a P(C) of 1.0. All of the data points in this central region fall below the predicted function indicating that NC performed at a somewhat higher level in discriminating his variable of 50 from a standard of zero than he did in discriminating it

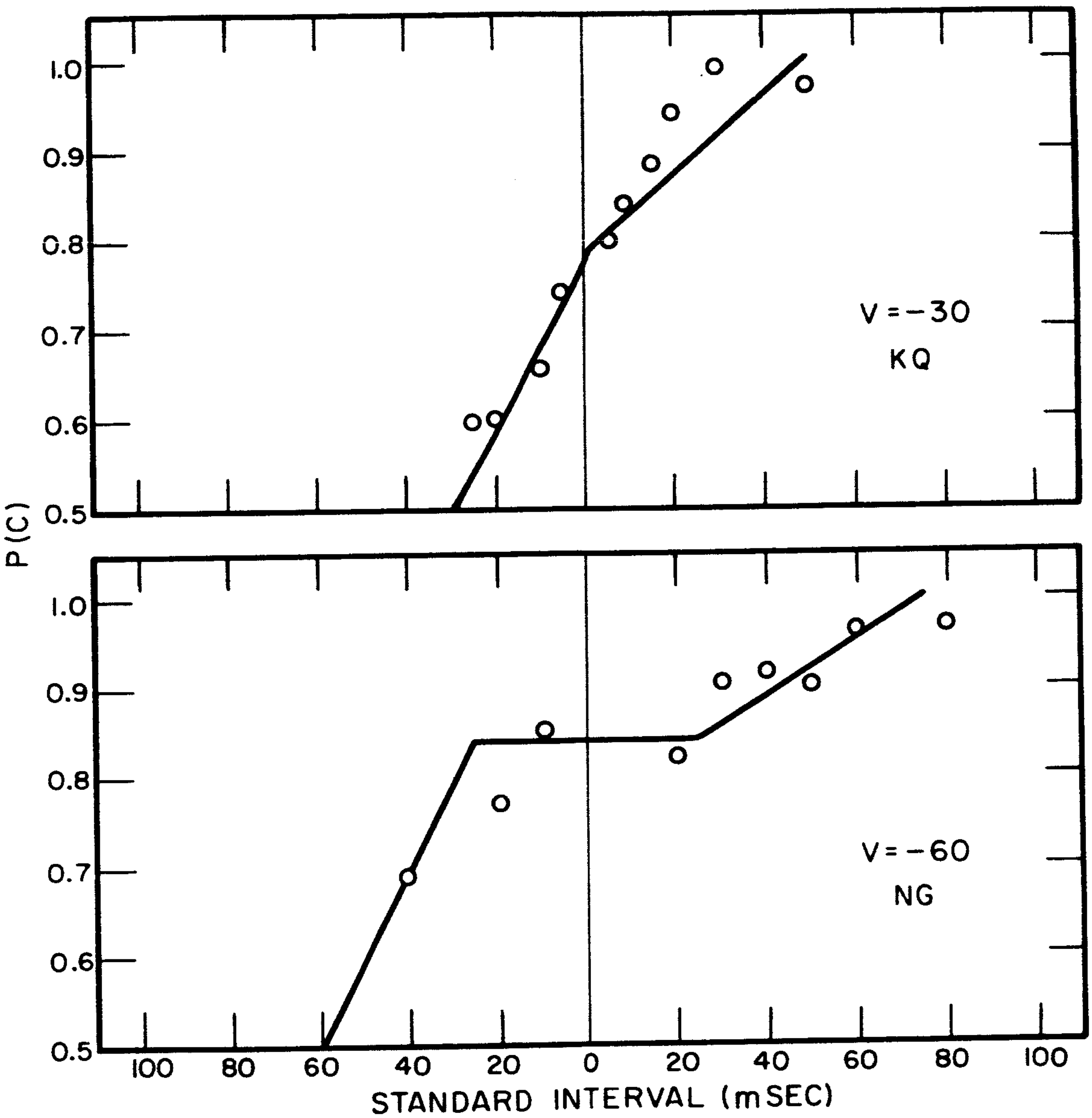


FIG. 13 OBTAINED DATA FOR PART B AND THE FUNCTION CALCULATED AS EXPLAINED IN THE TEXT. SUBJECTS K.Q. AND N.G.

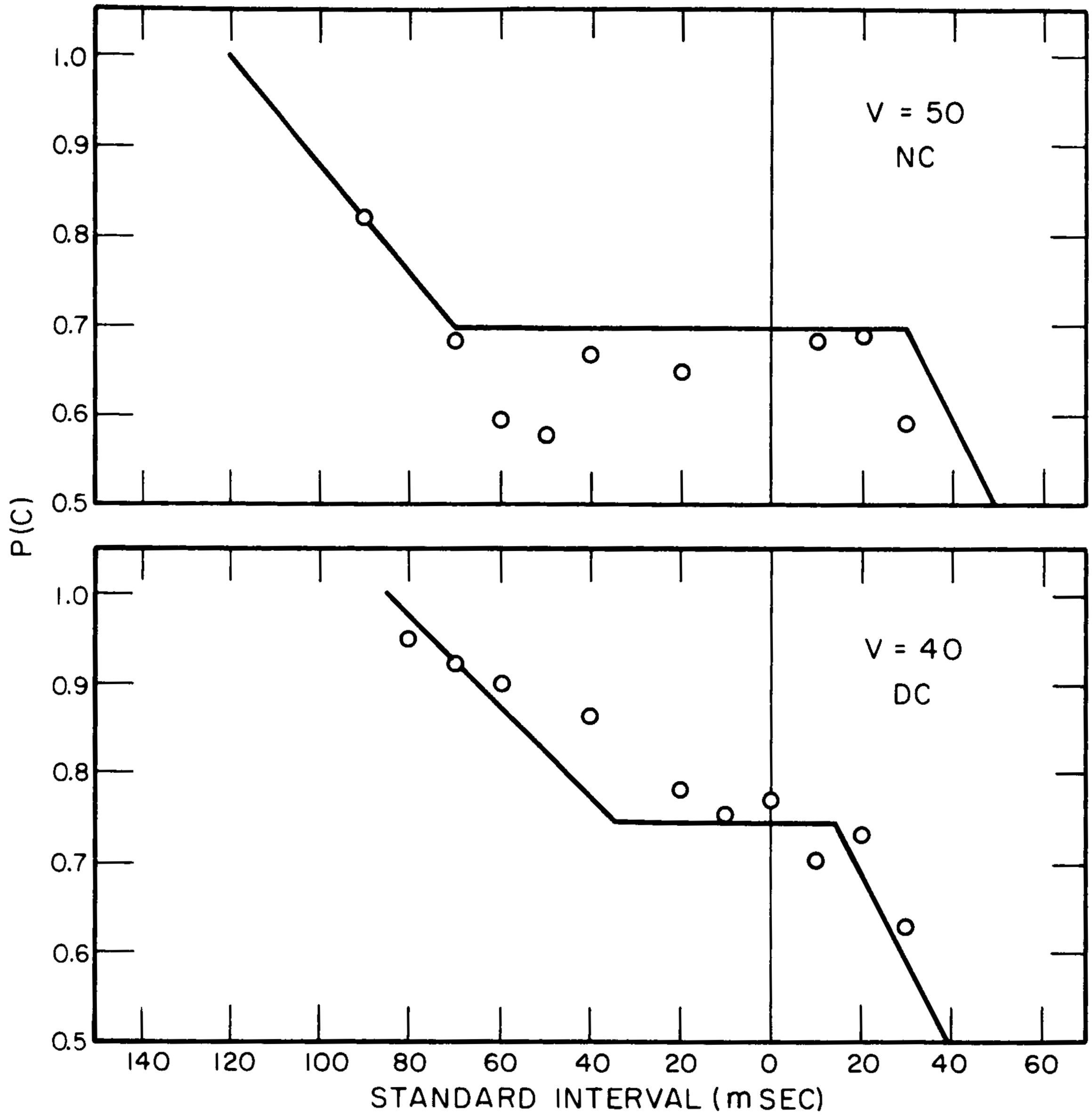


FIG. 14 OBTAINED DATA FOR PART B AND THE FUNCTION CALCULATED AS EXPLAINED IN THE TEXT. SUBJECTS N.C. AND D.C.

from a standard of the various non-zero values which fall in this range.

Subject KQ shows no flat central region. Clearly, he is better described by counting model A in this experiment as he also was in Experiment 1. His predicted function in Figure 13 is calculated from counting model A which gives a value of x of 1.6 for the assumed M of 50 and the obtained P(C) for the zero standard of .784. The predicted function does not fit well on the positive side and this discrepancy is an important one which will be analyzed more fully in the next section.

The remaining two subjects are fairly well fit by the attention model, i.e., they both span two quanta on the side of x opposite to their variable interval and the center one-quantum span is probably flat although in both cases more data points would be needed to determine this with certainty. It should be pointed out that the predicted function for NG (Figure 13), which fits his data quite well, leads to the conclusion that his x was -25 msec. in this experiment and that he failed to discriminate between intervals coded (0) and those coded (+1). In terms of the attention theory, this implies that (a) he attended to the auditory channel with a probability of one, the first time this has emerged as a conclusion from any successiveness data, and (b) conduction from the signal source to the display area was faster in the visual channel than in the auditory. This latter conclusion has not been observed previously either; x has invariably been positive in other data. These unusual results will be discussed in the next section.

The parameter M has been found to be significantly different for different individuals in previous studies (3) and it should be emphasized that a single value of it, 50 msec., was used for all subjects in calculating the predicted functions in Figures 13 and 14. If individual differences in M were taken into account, the agreement between theory and data would be somewhat improved.

Summary of results.- In Experiment 1, as in all previous experiments, probabilities of discriminating a time interval between two independent signals from an objectively zero time interval were studied and the results have been interpreted in terms of a quantal conception of psychological time. In the present experiment, probabilities of discriminating one non-zero interval from a second non-zero interval have been examined. The results are in general agreement with a quantum theory and a quantum of approximately 50 msec. still seems to be a valid inference. However, there are marked differences in the way the quantum mechanism is utilized by different subjects in this more complex task.

For two of the five subjects there is a range of two quanta bracketing simultaneity within which all intervals are equivalent to an interval of zero. For two others, this interval of simultaneity is one quantum in width. For the fifth it is zero.

This finding, plus certain other aspects of the data of Experiment 2, cannot be explained by the assumptions of attention theory which have hitherto been sufficient. Some expansion of the theory is required and an initial step in that direction is taken in the next section.

Discussion

The theoretical quantity x is the difference between the conduction times of two sensory channels. By conduction time is meant the time which elapses between the occurrence of the external signal and the arrival of the message produced by the signal in the display area. This latter term, "display area", is a logical construct which remains imprecisely defined.

Conduction time might be thought of as a constant delay for a simple sensory signal providing that the physical characteristics of the signal and the state of the sensory system are unchanging. That is, it might be constant in a statistical sense. However, it is probably more reasonable to assume that it is not a fixed value, at least in the ways in which it enters into a psychophysical theory. Even a unidimensional change in a signal may give rise to a set of messages within the central nervous system rather than just a single message and the latencies associated with the various members of the set may differ; i.e., a single signal may produce a set of messages which are widely dispersed in time, and probably also in space. If this is so, and the study of evoked cortical potentials suggests that it is (5), then it would be more realistic to think of multiple display areas for each of which conduction time may be different. Different psychophysical tasks, in turn, might involve different display areas and the value of x would then be different for the different tasks even though the signals were the same. There would be a set of conduction times among which the neural information processing mechanisms might choose and this choice might be governed in part by outcome and feedback. Information might be selected from that display area which has a latency which in some manner optimizes performance.

Evidence that x may assume different values for a given set of signals depending upon the experimental task is beginning to accumulate. That conduction is slower in the visual modality than in the auditory, at least for signals of moderate intensity, is implied by the difference in mean simple reaction times between the modalities which has frequently been reported to be in the neighborhood of 40 msec. (6). For the tone and light which have been used throughout our experiments, this difference is about 30 msec. when one compares detection reaction times with knowledge of channel given in advance (2). It is important to note in this connection that the variances are not different for the two channels. Furthermore, a difference in conduction time of about this magnitude (40 msec.) appears also in the averaged evoked potential recordings reported by Sutton _et al_. (5). It is as if the display area which has the shortest latency is selected when rapidity of response is the major criterion of performance.

When discrimination reaction time is measured, using the same two signals as were used in the detection task, the value of x defined again as the difference in mean reaction time between the two channels for the certainty condition, is reduced to about 10 msec. And again the reaction time variances are the same for the two channels. A value of x averaging 5 to 10 msec. is also found in our measurements of successiveness discrimination using a standard with an interval of zero as was seen in Experiment 1 of the present paper and as has been reported previously for other similar experiments (2).

Finally, in Experiment 2 above we have found evidence for other values of x, the most extreme case being that of subject NG whose data are most satisfactorily explained by assuming a rather large, negative value of x (-25 msec.). His x in Experiment 1 was approximately 20 on the positive side. Similarly, the value of x for NC was 3 msec. in Experiment 1 and 31 msec. in Experiment 2. Subject DC showed little difference in x between the two experiments and the results for KQ will be discussed more fully in a moment.

These results suggest that x can assume different values under different conditions and they also open up the possibility that variations in x within a single experiment may be an important source of variance which must be considered in all of our measurements. The possible effects of variations in x should be explored theoretically.

If x varies significantly during an experiment, the general effect upon the successiveness discrimination function of attention theory can be seen rather easily by referring back to Figure 1. Changes in x would cause the function to move laterally while the slope of the ascending segments would be unchanged. This would introduce two major distortions into the function. The center, flat segment would be reduced in size so that it would span less than one M on the abscissa. This deduction agrees with the obtained result as can be seen in Figure 10 and Table VI. The second effect would be to lessen the slope of both ascending segments which would lead to estimates of M which are biased in the direction of being too large. In (3) some evidence is presented which indicates that M is correlated over individuals with the alpha half-cycle and that the absolute values of the two quantities seem to be the same for individuals at the small M end of the scale. However, individuals above the median of M yield values of M which are significantly greater than the alpha interval. This bias might be due to variations in x.

Referring back again to Figure 1, variations in x would distort the ascending segments by bending them at either end, rendering them more sigmoid in form. This would probably have some effect on the total span of the distribution, the y and y(-) distance, but the relative effect on the total span would be less than the effect on the span of one of the ascending segments. And, in fact, Table VI indicates that the average total span is somewhat less than three times the span of the positive ascending segment. This aspect of the argument is only qualitative, however, and under certain conditions it might not hold.

The finding that the negative ascending segment has a somewhat larger span than does the positive cannot be accounted for by the hypothesis of a variable x.

So much for the effect of x upon the successiveness function in which a non-zero interval is to be discriminated from an interval of zero. Now its effect upon the probability of discriminating between two non-zero intervals will be analyzed and this will be done using the terms which were developed to describe the second experiment. P(C) is a function of V, the interval of the variable, S, the interval of the standard, M, the hypothetical time quantum size, and x.

Figure 15 shows how these quantities interact according to the attention theory (the top figure) and according to counting model A (the lower figure). The abscissa is expressed in units of M and for the example V is set equal to .6M. For a particular value of x, the function consists of the branch labeled with the chosen value of x plus that part of the heavy line which is to the right of its juncture with the relevant branch.

In the top figure, as x decreases beginning with a value equal to V, the flat center segment, which spans one M, rises proportionately until x reaches the value (V - M) at which the function is the entire heavy line. For still more negative values of x, the function in the upper figure becomes identical to that in the lower figure.

According to the counting model, the lower figure shows that when x equals V, the heavy line is the function and as x decreases the left-hand segment moves up and to the left until, when x equals (V - M), it is again the single heavy segment. This cycle is then repeated as x becomes increasingly negative.

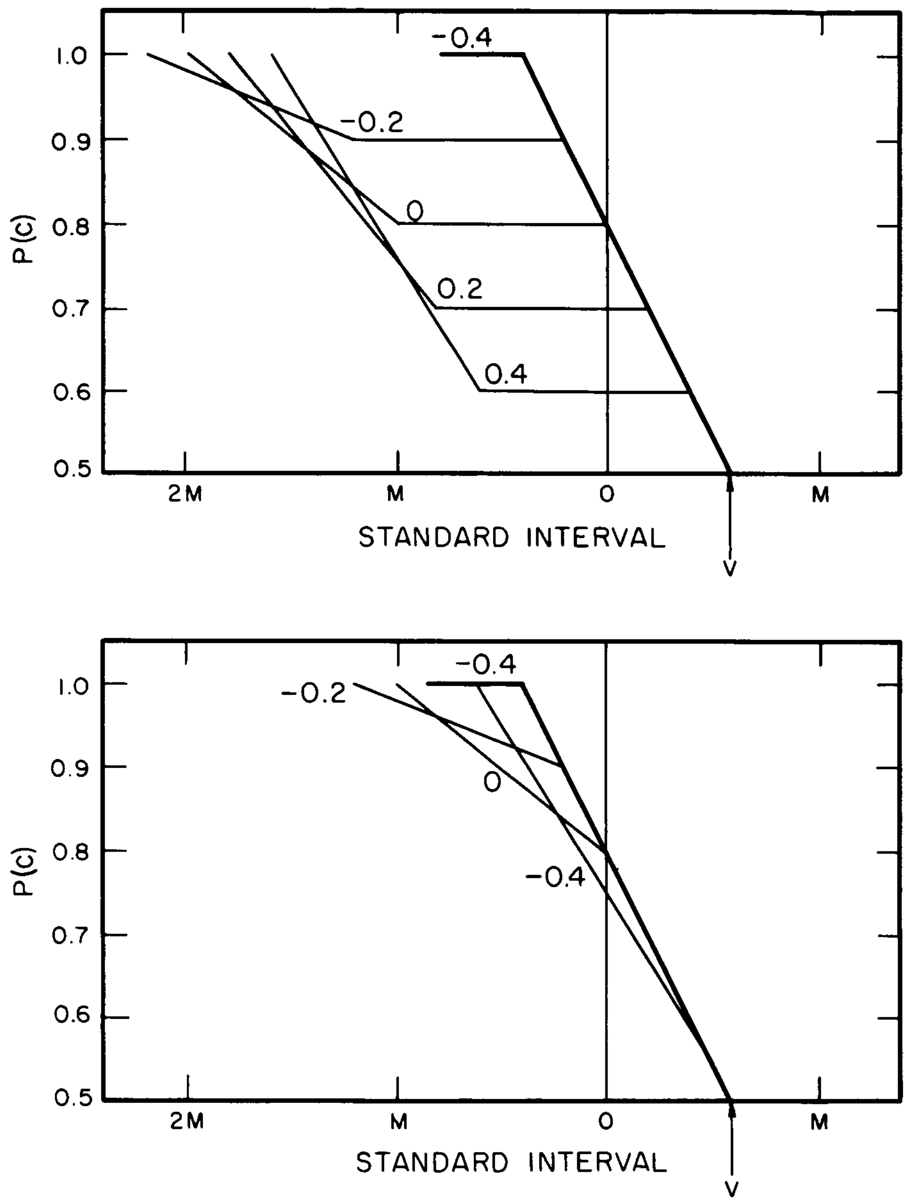


FIG. 15 THE EFFECT OF VARIATIONS IN x UPON THE FUNCTION RELATING P(c) FOR A VARIABLE OF 0.6 M TO THE INTERVAL OF THE STANDARD.

TOP. ATTENTION THEORY
BOTTOM. COUNTING MODEL A

THE HEAVY LINE IN EACH FIGURE IS PART OF EACH OF THE OTHERS TO THE RIGHT OF THEIR JUNCTURE. THE NUMBERS INDICATE VALUES OF x IN UNITS OF M.

The counting model is symmetrical around zero, that is, if V is negative then the entire family of functions is rotated around the zero axis. The upper figure is symmetrical also if $P_s = 1$ when a negative variable is employed. However, if P_ℓ remains unity, as seems to be the usual case, then the family of functions for a negative V is the same for the two models.

These derivations have some important consequences. For example, when V is chosen (or when x assumes a value) so that (V - x) equals M, then the function should be the same, single linear segment, the heavy line, according to both models. It has been shown that one subject may conform to one model and another subject to the other. If V is properly selected, then the same function should be obtained independently of which mechanism is involved.

It has been shown that x is typically about 10 msec., at least in the usual successiveness experiment, and that M is approximately 50 msec. This implies that an experiment in which one measured P(C) for a variable of -40 versus values of the standard to the right of -40 should yield a function which is linear over most of its length and which should intersect P(C) = .50 at -40. These conditions were most closely met for subject KQ in Experiment 2 who was assigned a variable of -30. His data, shown in Figure 13, are in fact extremely well fitted by a single straight line extending between -30 at P(C) = .5 and +29 at P(C) = 1.0. This implies that M is, for him, about 59 and that his x was about 30 in this experiment.

The implications of Figure 15 need to be brought out more fully. It shows that if x varied between the limits of -.2 and -.4 during the course of an experiment, this variation would have no effect at all on values of P(C) less than .90. And further, the line drawn through proportions less than .9 would have to pass through V at P(C) = .5. The majority of the data points would be free of variance contributed by x and they would have to be used to determine only one parameter of the line.

In the past, measurements of M have utilized a standard interval of zero. In that procedure, variance in x should be reflected in every data point. And the data points are used to determine both the slope and the intercept.

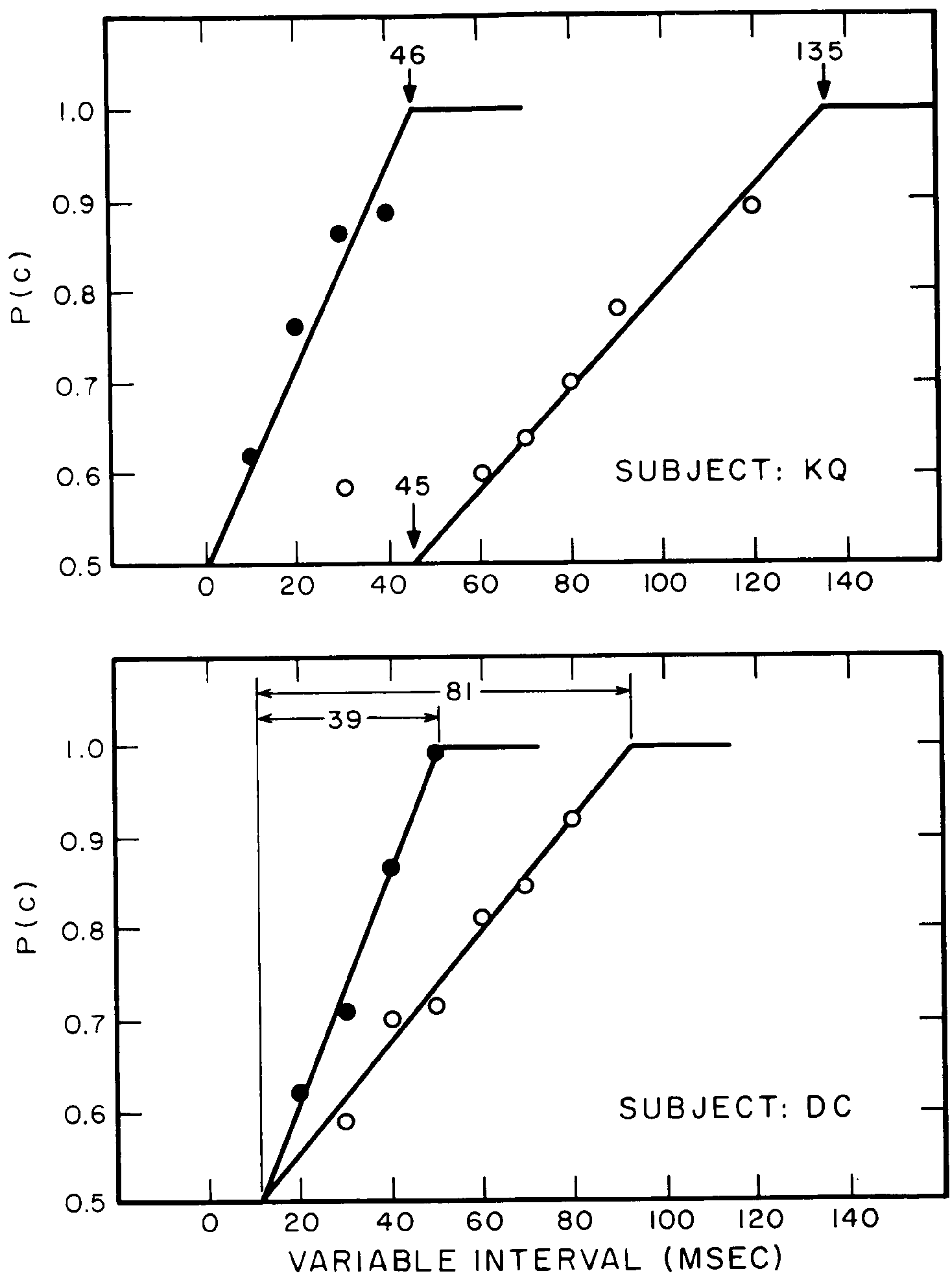
Thus, for the purpose of measuring M a revised procedure seems to be called for. Since x can assume a value which is small and positive for nearly all subjects, a standard which is relatively large and negative should be used. A standard of -35 would permit x to fluctuate between about 5 and 15 msec. without affecting values of P(C) less than .9. Thus, the standard should be less than x by an amount approaching M and the majority of the values of the variable should fall between them. The subject should be instructed to pick the pair in which the sound terminates before the light, being scored correct when he designates the standard. Such a procedure might yield estimates of M which are more free of bias than those obtained previously and which are also more reliable. Such a procedure needs to be tried; it might make it possible to obtain a satisfactory estimate of M with much less data than are required at present.

An Incidental Observation: Quantal Shifts in Performance

During the early experimental sessions of Experiment 1 large shifts occurred in the performance of two of the subjects. These individuals, KQ and DC, were the two subjects in Part B who were presented with a standard of zero and only positive values of the variable interval in their initial sessions. This condition prevailed for twelve sessions during which their performance showed the usual minor changes from one day to the next. The open circles in Figure 16 represent the data which were obtained during this period. The lines were calculated from the data in the usual fashion and indicate that x and M, respectively, were 45 and 90 for KQ and 12 and 81 for DC.

Following the twelfth session, experimental conditions were changed for both subjects. Later, they were remeasured under the initial condition and the performance shifts became evident. The filled circles in Figure 16 show their performance following the shift. The values of x and M are now 0 and 46 for KQ and 12 and 39 for DC. Actually, the post-shift line for KQ indicates a small and negative value for x but since P(C) must be .5 at an interval of zero, his line in this case was calculated by fixing x at zero.

Both subjects changed greatly in the period between the two measurements. For both of them the slope of the line doubled; the value of M changed from 90 to 46 for KQ and from 81 to 39 for DC. And x decreased by about 45 for KQ, although it remained within one msec. of its previous value for DC.



G.16 SHIFTS IN PERFORMANCE OBSERVED DURING EXPERIMENT 1. OPEN CIRCLES ARE EARLY SESSIONS, SOLID CIRCLES ARE LATER SESSIONS. ALL LIGHT-FIRST, CERTAINTY.

The performance shifts occurred after day 12. On day 13, both subjects began a ten-session period during which both positive and negative variable intervals were presented with uncertainty as to which would occur on each trial. DC shifted to his higher performance level on day 13 and remained there from then on. KQ, on the other hand, continued at his lower level during all ten days. Then a series of sessions with only negative variable intervals, under certainty, were begun, and it was during this series that KQ finally changed.

These facts suggest that the performance shifts are unlikely to occur under constant experimental conditions and that a pronounced change in the nature of the experimental task seems to favor their occurrence. In both cases they happened very soon after an increase in the requirement to be set for the auditory signal occurring before the visual signal. This consideration has a methodological implication, namely, that training sessions which are conducted to prepare for the measurement of M probably should include a few sessions under a variety of conditions, at least early in the practice series.

These performance shifts have theoretical relevance as well. They are one more item of evidence favoring a quantal interpretation of psychophysical time. In both cases the span of the function decreased from two quanta to one quantum and in one case the value of x may have decreased by one quantum as well. This interpretation implies a quantum size of 45 msec. for KQ and about 40 msec. for DC. In a previous study (3) in which the quantum size was measured using three independent methods, it was found to be 45.7 for KQ and 41.3 for DC, in excellent agreement with the present results.

The nature of these quantal shifts cannot be explained as changes in the criterion of judgment. A change from a two-quanta to a one-quantum criterion would be expected to affect x but to leave M unchanged. Some other interpretation is demanded by the data.

I have concluded previously (3) that one of the functions of the time quantum generator is to control the duration for which a neural message must dwell in a given stage of the information-transmission pathways. In accounting for the shape of reaction time distributions it has been necessary to postulate two ways in which this may occur: a message may be delayed within a stage for either (a) exactly one q or (b) a duration equally-likely to be any value from zero to q. The results shown in Figure 16 can be accounted for very easily in this general way, and, furthermore, the accounting is consistent with and illuminates the interpretation of Experiments 1 and 2 which was given above.

This requires postulating that "stages" can be added or deleted in the pathway leading into the central data processor. If a stage of type (b) were added in the visual channel, the result would be to cause x, the difference in conduction time between the visual and the auditory channel, to vary with a rectangular distribution between the limits x and (x + q). The effect of this variation on the successiveness function would be to halve its slope, increasing M from one to two q. The resulting function would still be linear.

Adding a delay stage of type (a) in the visual channel would simply increase x by one quantum.

Thus, the results reported in this section can be accounted for in terms of concepts which were formulated earlier. The one-quantum decrease in M may be due to the deletion, or by-passing, of a type (b) stage in the visual input channel and the one-quantum decrease in x could result from the deletion of a type (a) stage in the same channel.

This general idea, that the logical structure of the information-processing pathway may change, is not wholly unreasonable. It has been observed before that under certain conditions three such stages appear to be interposed between signal and reaction time response while under other, slightly different conditions, the number of stages is four (7).

In the discussion section above, the question of variation in x was explored under the tacit assumption that such variation is continuous in nature. The discussion in the present section offers the hint that variation in x may also be quantal and that it, too, is under the control of the time quantum generator. These points of view need to be examined more fully in future research.

APPENDIX A

Raw Data for Experiment 1, Part A

Number of Correct Responses/Number of Presentations

Channel Uncertainty in All Cases

Subject GK		Subject JH		Subject PM		Subject JC	
Variable Interval (msec.)		Variable Interval		Variable Interval		Variable Interval	
-40	258/264	-90	390/420	-95	97/100	-80	279/378
-30	238/264	-85	121/139	-80	338/364	-70	129/180
-20	177/264	-70	654/842	-70	226/298	-50	240/378
-10	148/264	-60	301/419	-60	204/264	-30	90/180
20	182/264	-50	272/421	-50	181/298	30	105/180
30	215/264	-45	84/140	-40	60/100	40	257/378
40	248/264	15	77/139	-30	46/100	60	144/180
40	243/264	20	190/280	-20	49/100	70	319/378
		30	223/280	-10	45/100		
		35	106/140	10	56/100		
		40	245/280	20	56/100		
				30	216/298		
				40	305/364		
				50	255/298		
				60	254/264		
				70	99/100		
				80	100/100		
				95	100/100		

APPENDIX B

Raw Data of Experiment 1, Part B

Number of Correct Responses/Number of Presentations

Subject DC			
Certainty		Uncertainty	
-70	164/168	-40	71/84
-50	133/168	-30	74/112
-40	307/420	-20	185/294
-30	160/252	-10	157/292
20	78/126	30	74/112
30	148/210	40	326/378
40	145/168	50	296/322
50	83/84		

Subject NC			
Certainty		Uncertainty	
-70	374/446	-70	118/126
-60	135/180	-60	73/84
-50	372/529	-50	300/378
-40	174/306	-30	182/294
-30	242/446	30	213/294
20	105/168	50	345/378
30	175/252	60	82/84
50	285/336	70	122/126
60	241/252		

Subject NG			
Certainty		Uncertainty	
-80	194/216	-60	67/84
-70	368/404	-50	79/112
-60	144/180	-30	235/364
-50	247/320	-20	191/336
-40	165/264	30	233/364
-30	270/446	40	237/336
-20	148/258	50	92/112
30	143/252	60	76/84
40	177/252		
50	204/252		
60	223/252		

Subject KQ			
Certainty		Uncertainty	
-50	159/180	-50	106/150
-40	146/180	-40	105/150
-30	139/180	-30	95/150
-20	123/180	-20	89/150
20	235/360	20	98/150
30	267/360	30	96/150
40	304/360	40	120/150
50	306/360	50	129/150

APPENDIX C

Data for Experiment 2, Part A
Number Correct/Number Presented for
A Variable Interval of 30 Msec. When Compared to
A Standard of Zero and When Compared to
The Standard Indicated in Column S. Subject JH.

S	Std = S	Std = 0	S	Std = S	Std = 0
-120	99/100	76/100	-40	170/250	270/350
-110	180/200	145/200	-35	78/100	79/100
-99	174/200	134/200	-30	82/100	78/100
-95	93/100	75/100	-20	80/100	77/100
-90	93/100	68/100	-10	78/100	75/100
-80	80/100	207/300	0		391/490
-75	86/100	77/100	10	77/100	76/100
-70	103/150	193/250	20	132/200	159/200
-60	363/500	336/500	25	109/200	141/200
-50	150/200	151/200			

APPENDIX D

Data for Experiment 2, Part B

P(C) for a Variable Interval of the Indicated Magnitude When Compared to a Standard of Zero (P_o) and When Compared to the Standard Indicated in Column S (P_s)

Each P is Based on 176 Responses

Subject KQ

Variable Interval = -30

S	P_s	P_o
-25	.60	.73
-20	.60	.68
-10	.66	.77
-5	.74	.76
5	.80	.80
10	.84	.84
15	.88	.80
20	.94	.86
30	.99	.82
50	.97	.79

Subject NG

Variable Interval = -60

S	P_s	P_o
-40	.69	.89
-20	.77	.85
-10	.85	.88
20	.82	.81
30	.91	.85
40	.92	.79
50	.90	.82
60	.96	.86
80	.97	.82

APPENDIX D
(CONT'D)

Subject **NC**

Variable Interval = 50

S	P_s	P_o
-90	.83	.74
-70	.68	.65
-60	.59	.74
-50	.58	.68
-40	.67	.73
-20	.64	.69
10	.68	.74
20	.69	.72
30	.59	.57

Subject DC

Variable Interval = 40

S	P_s	P_o
-80	.95	.76
-70	.92	.71
-60	.90	.75
-40	.86	.80
-20	.78	.79
-10	.76	.69
10	.70	.76
20	.74	.76
30	.63	.70

REFERENCES

1. Schmidt, M. W., and Kristofferson, A. B.: Discrimination of Successiveness: A Test of a Model of Attention. Science, 139, 3550, Jan. 11, 1963, 112-113.

2. Kristofferson, A. B.: Attention in Time Discrimination and Reaction Time. NASA CR-194, 1965.

3. Kristofferson, A. B.: A Time Constant Involved in Attention and Neural Information Processing. NASA CR-427, 1966.

4. Kristofferson, A. B.: A Next Stage in Human Information Processing: Attention. Paper presented to joint meeting of Psychonomic and Psychometric Societies, October, 1964.

5. Sutton, S.; Braren, M.; John, E. R.; and Zubin, J.: Evoked Potential Correlates of Stimulus Uncertainty. Paper presented at meetings of American Psychological Association, September, 1964, Los Angeles.

6. Woodworth, R. S., and Schlosberg, H.: Experimental Psychology. Rev. Ed. Henry Holt and Company, New York, 1955.

7. Kristofferson, A. B.: A Quantal Interpretation of Sensory Channel Uncertainty and Reaction Time; and, The Psychological Time Quantum and the Discrimination of Succession. NASA CR (in press), 1965.

NASA-Langley, 1966 CR-454