

Semiannual Report, Contract Nonr-3579(04) (U)
1 December 1964 through 31 May 1965
Supported by Fund Transfer R-129 from
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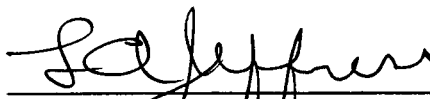
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Quarterly Status Report,
NASA Contract R-129-09-030-017 (U)
1 March 1965 through 31 May 1965

14 July 1965

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Prepared by L. A. Jeffress and C. S. Watson



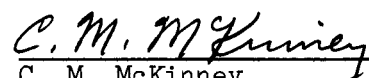
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Semiannual Report for Contract Nonr-3579(04)
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by

Lloyd A. Jeffress and Charles S. Watson

I. Status of Proposed Problems

A. Problem 1-a. Receiver Operating Characteristics for Visual Detection
(Ann Tucker and R. B. Evans)

Data from this study are being examined statistically to determine the optimal method of combining day-to-day blocks of data and to discover, if possible, what undesired sources of variance can be eliminated from the rating scale procedure.

Problem 1-b. Psychophysical Studies of Brightness
(G. H. Jacobs and H. A. Gaylord)

A series of studies on some characteristics of perceived brightness are presently being planned, and the appropriate apparatus is under construction. The focus of interest in these studies involves the general case where the brightness response to a transient shift in the luminance of a visual stimulus is obtained when both increments and decrements in light input are provided. Parameters of interest include both the magnitude of the stimulus shift and the adaptation condition from which the shift is made. The impetus for these studies came from some results of physiological experiments which raised the question as to how the visual system operates in detecting changes about an adaptation state, and the further question as to the nature of the slopes for changes in brightness as a function of the adaptational variable. A pilot study has been run in which a number of subjects estimated the brightness of flashed increments and decrements in stimulus luminance for several different adaptation conditions. There were

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two obvious results from these observations: (a) the method of magnitude estimation appears to be one technique with which it is possible to obtain reliable estimates of brightness from relatively naive subjects in this kind of task, and (b) the slope of the brightness function is highly dependent on the luminance of the region surrounding the test area relative to the luminance of the test region (in addition to the experimental variables that were specifically examined). In short, the amount of induction provided by the surround--test region interaction is also a powerful feature of the situation.

We are, therefore, about to embark on two kinds of experiments. In the first we plan to examine carefully the nature of the brightness function for a range of stepped increments and decrements from a variety of adaptation conditions in the case where the possibilities for induction effects are minimized by using a stimulus situation where the adaptation and test lights diffusely illuminate the whole eye; secondly, we propose to make the same kinds of measurements where the luminance of the surround of the test field is systematically varied over a large range. We hope to obtain information about the shape of the brightness function around a number of adaptation states, to examine the detectability of increments and decrements in stimulus luminance as a function of the adaptation variables, and to examine quantitatively the effects of induction under these various stimulus conditions.

Problem 1-c. Physiological Studies of Brightness
(G. H. Jacobs and H. A. Gaylord)

Considerable time has been spent analyzing data collected previously from experiments in which single-cell activity from fourth-order elements in the monkey visual was recorded. The elements under investigation in those experiments were those shown to function in the conduction of visual information signaling the brightness of a visual stimulus. The results of these experiments were presented orally at the spring meeting of the Optical Society of America. The published abstract of that talk follows:

LATERAL GENICULATE RESPONSES TO SHIFTS IN LIGHT INTENSITY:
ADAPTATION EFFECTS

Gerald H. Jacobs
Department of Psychology and Defense Research Laboratory
The University of Texas

[J. Opt. Soc. Amer., 55, 613-614, 1965]

Single units in the lateral geniculate nucleus of the monkey which transmit information about the brightness of a stimulus light are of two types; some show an increase in firing rate to all spectral stimuli (broad-band on cells), others respond with a decrease in firing rate (broad-band inhibitors). The behavior of these two classes of cells in response to stepped shifts in light intensity, both increments and decrements, from a given adaptation intensity has been examined. The on cells respond with an increase in firing rate to increments in stimulus intensity; they respond with a decrease in firing rate to decrements in stimulus intensity. Inhibitory cells behave in the opposite manner. The response to a specific stimulus intensity is dependent on the intensity of the adaptation light. The relationship between firing rate and the size of the stimulus shift shows characteristic changes as a function of the adaptation intensity. The total range of shift intensities over which any cell shows good differentiation is usually not more than ± 1 log unit around the adaptation intensity. An index of the discriminatory ability of these cells has been derived, based on the differences between the inhibitory and excitatory responses for any given stimulus shift.

Major effort has been devoted toward establishing a laboratory in which it will be possible to study physiological aspects of the visual system by means of single-cell recording. The general kinds of experiments that will be done will be directed toward the problems of understanding the nature of the mechanisms for coding spatial, wavelength, and intensity aspects of the visual input as seen at several levels in the squirrel monkey visual system: optic tract, lateral geniculate nucleus, and superior colliculus. As in any such venture numerous problems are being encountered but it is anticipated that experimental work will be underway shortly.

B. Problem 2. Signal Detection as a Function of Vigilance
(C. S. Watson and T. L. Nichols)

Instrumentation for recording autonomic system responses (GSR) in a vigilance situation is nearly completed and work on the experimental program will begin shortly.

C. Problem 3. Signal Duration and the Width of Critical Bands
(W. T. Bourbon and L. A. Jeffress)

Work on one phase of this problem has been completed. A paper covering part of the findings, written for presentation at the June meeting of the Acoustical Society of America, is attached as Appendix A to this report. The complete findings will be used as material for a Doctor's Dissertation and will be published in the Journal of the Acoustical Society of America.

Filters have been ordered to permit approaching the critical band from one side at a time in order to obtain a better idea of both its width and its shape. Work on this aspect of the problem will begin as soon as the filters have been delivered.

D. Problem 4. Detection of Minimal Signals in the Absence of External Noise
(C. S. Watson)

Further work on this problem is awaiting the outcome of a related methodological study.

E. Problem 5. Detection by Multiple Observers

As mentioned in earlier reports, data for this study are being gathered in connection with the other problems. They continue to indicate the superior performance of the "multiple observer" over the best of the four subjects, but no formal presentation of the results is appropriate at the present time.

F. Problem 6. Detection and Response Latency
(C. S. Watson)

These experiments were completed during this period. A paper on this work, written for presentation at the Acoustical Society of America meeting, in Washington, D. C., is included in this report as Appendix B.

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G. Additional Work
(L. A. Jeffress)

As work performed partly under this contract and partly under BuShips Contract 72627 and 93124, two chapters of a book to be entitled Modern Foundations of Auditory Theory, edited by J. V. Tobias and E. D. Schubert and to be published by Academic Press, have been written and issued as DRL Acoustical Report No. 245. The report is issued under the title, "Masking and Binaural Phenomena," by Lloyd A. Jeffress.

APPENDIX A

EFFECT OF BANDWIDTH OF MASKING NOISE ON DETECTION
OF HOMOPHASIC AND ANTIPHASIC TONAL SIGNALS

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Department of Psychology and Defense Research Laboratory
The University of Texas, Austin, Texas

The effect of the bandwidth of a noise masker on detection of homophasic and monaural tonal signals has been examined many times. A growing number of researchers has made use of the band-narrowing technique to obtain measures of the monotic and diotic critical bandwidth (CBW). In addition, the problem has been attacked through studies of critical ratio, of loudness summation, and of frequency discrimination.

The dichotic or antiphasic CBW, however, has received little attention. In The Journal, in 1964, Langford and Jeffress suggested that the CBW for antiphasic detection might be wider than that for detection in the homophasic condition. Their suggestion was based on two findings. The first was that, in calculating the auto-correlation for noise which has a time-delay in the channel to one ear, an assumed bandwidth of 100 cps brings their function relating MLD and noise correlation at the two ears into agreement with that of Robinson and Jeffress. They had reduced the correlation by using noise from two additional generators. Their earlier assumption of a 50-cps bandwidth gave a poor fit to the Robinson-Jeffress data.

The second observation by Langford was that, in a band-narrowing experiment, detection of antiphasic tonal signals began to improve at external noise bandwidths of about 400 cps.

The present paper presents the results of a study which replicates and extends the observations by Langford and Jeffress concerning external noise bandwidth and antiphasic detection.

The signal used was a 500-cps tone with a duration of 150 msec, gated with a rise-fall time of 25 msec. The masker was thermal noise with spectral levels of 50, 45, and 30 dB. The bandwidth of the masker was varied from 2900 cps to 12.6 cps. Eleven bandwidths were used at the 50-dB spectral level, and six at 45 and 30 dB.

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Bandwidths from 2900 to 185 cycles were obtained by cascading two Khron-Hite filters while bandwidths from 160 to 22 cycles were obtained from very steep-skirted filters built to order. The 12.6-cps filter was a single-tuned filter.

In the early stages of the experiment, both subjects detected a tonal signal outside the masking-noise when the external bandwidth was narrow. The second harmonic of the signal frequency was found to be the culprit. With the signal level set at the highest value used in the study, the unwanted harmonic measured 0.01 mV, exactly what would be expected from the distortion listed in the specifications of the oscillator used--which, by the way, has one of the lowest distortions commercially available.

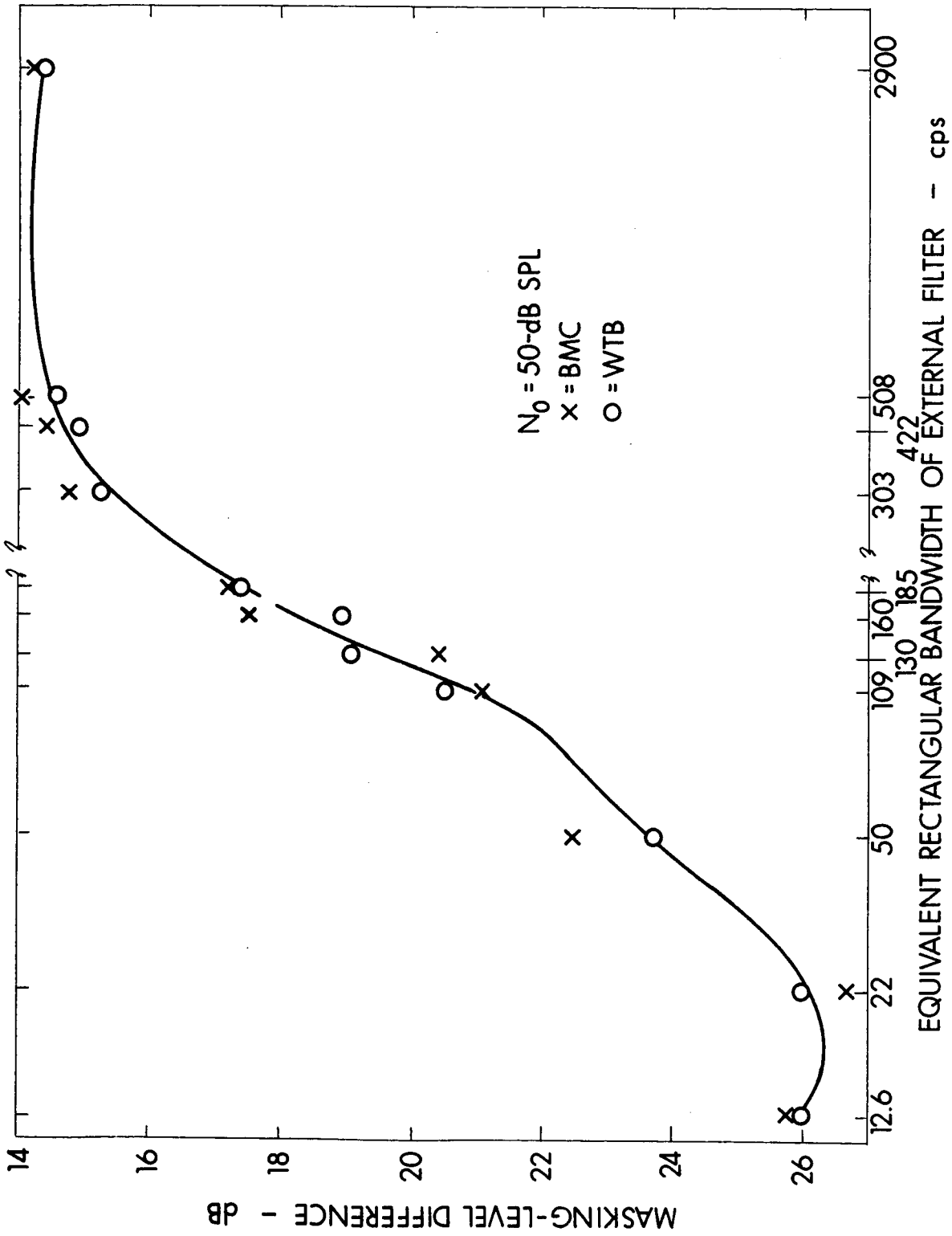
The only means by which we were able to remove the 1-kc tone from our detection task was by masking it. In all conditions run in the study, a wide band of noise with its spectral level 40 dB down from that of the narrow-band masker was used. The low-level noise was taken from the same noise generator as that used for the noise of higher level.

A two-interval forced-choice procedure was used. In order to obtain MLD's, the signal level necessary to produce a d' of 1.5 [$P(c) = 85\%$] was determined for the diotic and dichotic conditions at each bandwidth.

MLD's obtained with a spectral level of 50 dB are shown in Dwg. AS 65-615-S. The equivalent rectangular bandwidth of the external filter is shown on the abscissa, while MLD is plotted on the ordinate. The line is a visual fit.

The MLD of 14.3 dB at an external bandwidth of 2900 cps is in good agreement with several earlier studies. The same MLD is obtained with an external bandwidth of 508 cps. Below that width, however, the MLD begins to increase as the band is narrowed and does so rather rapidly as external bandwidth is further reduced.

That there is any change at all in MLD is an indication that the ear's bandwidths for diotic and dichotic detection are not the same. If they were, the MLD function would be a horizontal line. That there is an increase in MLD indicates



MASKING-LEVEL DIFFERENCE AS A FUNCTION
 OF EXTERNAL BANDWIDTH OF MASKING NOISE

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that below an external bandwidth of about 400 cycles, a given band of noise is less effective as a masker for NO $S\pi$ than for NO SO.

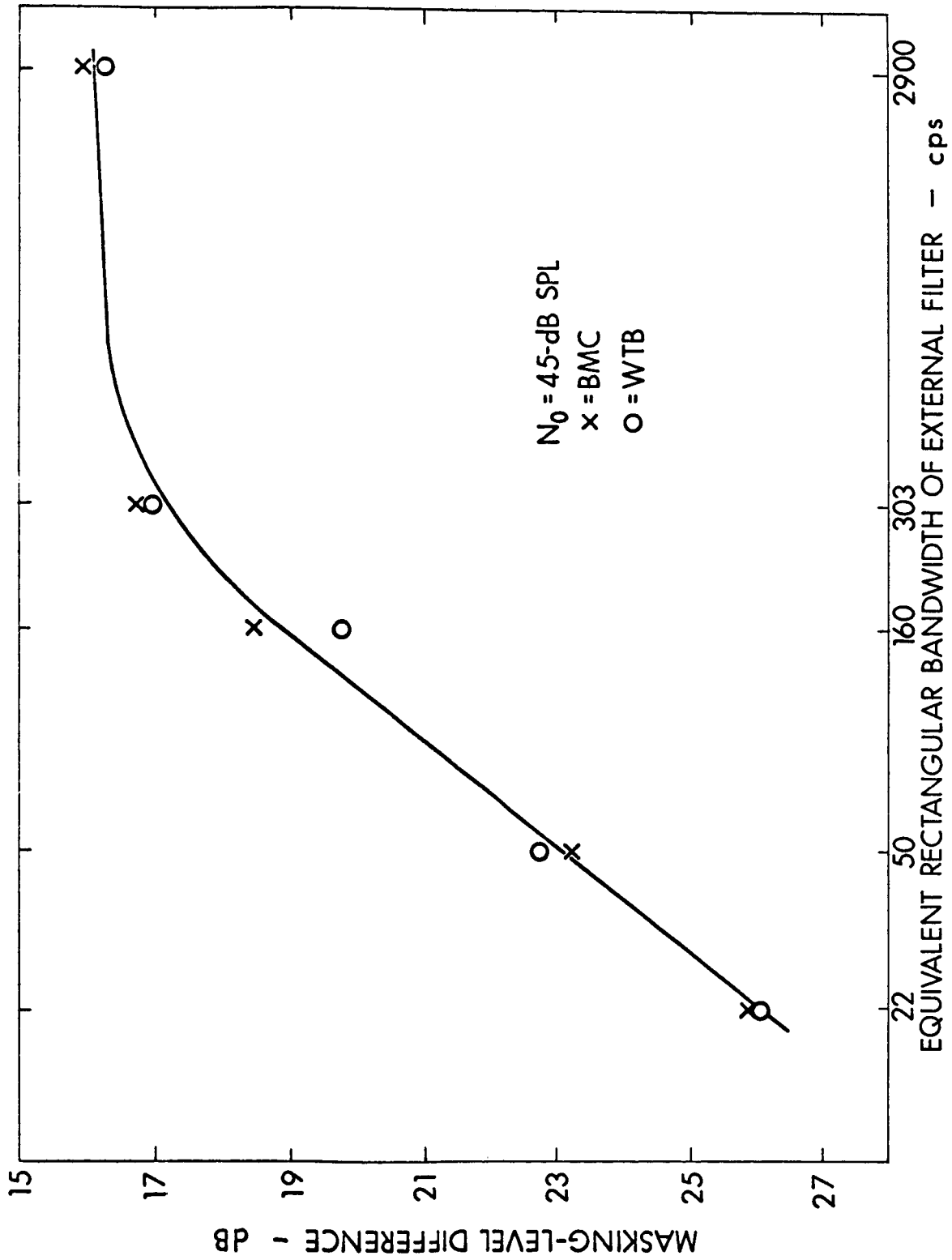
The leveling-off of the function at the MLD for an external bandwidth of 22 cycles was at first puzzling. The bandwidth of the pulsed signal is about 7.5 cps, so the 12.6-cps bandwidth should not be too narrow for the signal duration used. The signal levels required for both NO SO and NO $S\pi$ are lower at the narrowest external bandwidth than at the 22-cps bandwidth, but the MLD is the same.

In Dwg. AS 65-614-S we see the results with a spectral level of 45 dB. They are essentially like those of the preceding drawing: the MLD begins to increase at an external bandwidth of about 400 cps. The point for a bandwidth of 12.6 cps was run on subject WTB and the point proved to fall at a value about 1 dB lower than that for 22 cycles.

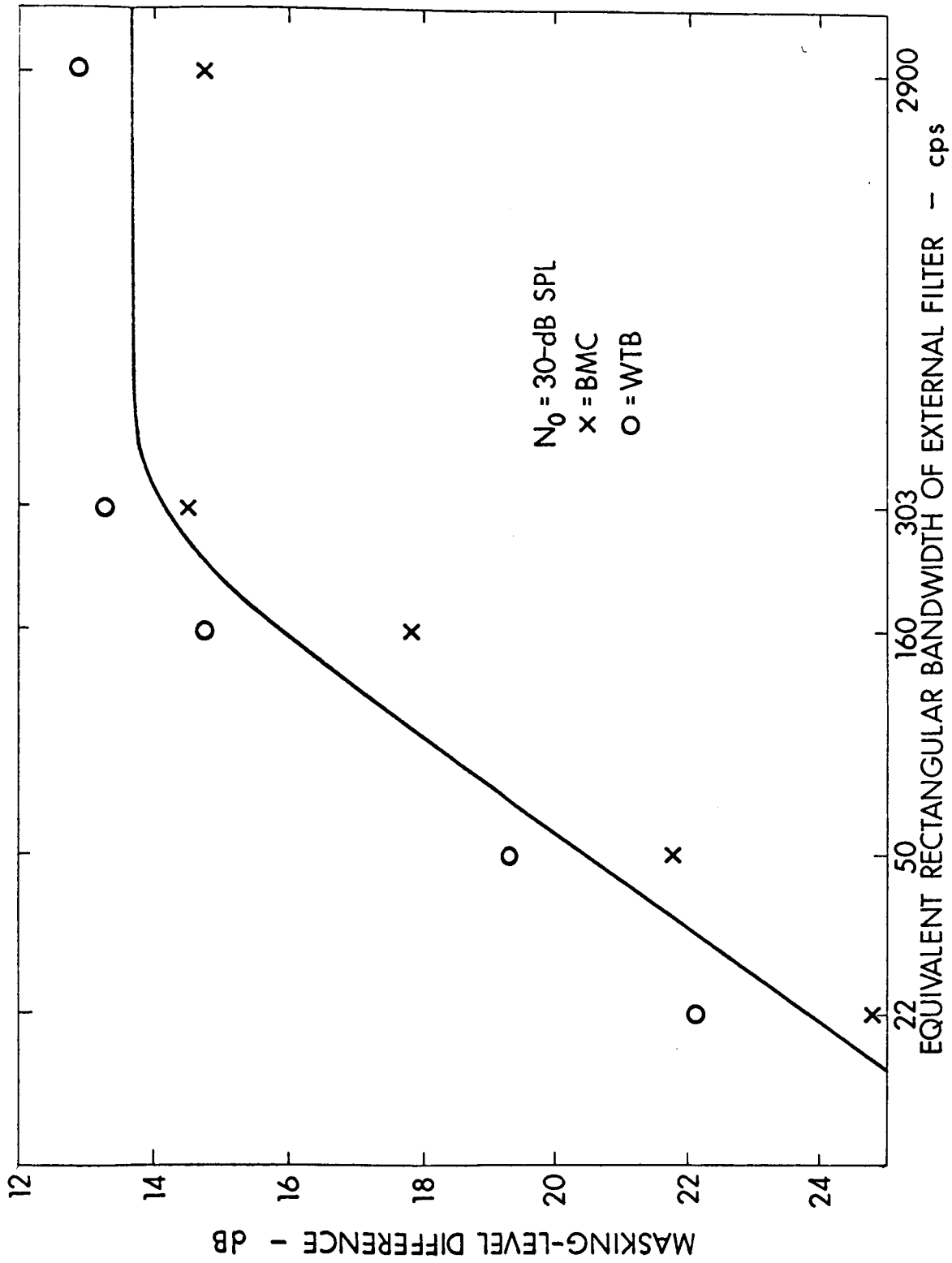
Drawing AS 65-613-S shows the results for a spectral level of 30 dB. Again, they may be seen to resemble those at the higher noise levels. For the subject WTB, the point not shown on the drawing, for an external bandwidth of 12.6 cycles falls at the same value of MLD as for 22 cps. This subject has a consistently lower MLD than does subject BCM at this spectral level. He required more intense antiphasic signals at all bandwidths.

Going back to Dwg. AS 65-615-S, where we can see the complete MLD function, we will return to the matter of the leveling-off of the function at narrow external bandwidths.

A function similar to ours for MLD is generated when one looks at the difference in power loss through two filters of different bandwidths but with the same center frequency. As the bandwidth of a third filter external to the two under consideration is narrowed, a point will be reached at which it begins to encroach on the skirts of the wider internal filter. At that time, a difference in power loss between the two filters shows up. If the internal filters about which we are talking are located in the auditory system, an MLD between the two filters will appear.



MASKING-LEVEL DIFFERENCE AS A FUNCTION OF EXTERNAL BANDWIDTH OF MASKING NOISE



MASKING-LEVEL DIFFERENCE AS A FUNCTION OF EXTERNAL BANDWIDTH OF MASKING NOISE

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As the external bandwidth is narrowed still more, the difference in power loss will increase at a rate determined by the shapes and widths of the skirts of the internal filters. When the external filter begins to encroach on the narrower of the internal filters as well as the wider, the resulting difference in power loss will be determined by the same two factors.

When the external filter has been reduced in bandwidth so that it is narrower than any peak or plateau shared by the two internal filters, the difference in power loss between the two will go to zero and any further reduction in external bandwidth will now result in equal power losses in both filters. If the internal filters are in the auditory system, the MLDs between the two filters will be constant. If the peak of the internal filter with broader skirts is narrower than the peak of the filter with narrow skirts, the difference in power loss will undergo a reversal. The "wider" filter will now lose less power than the "narrower." The function for MLD would reflect this reversal.

We believe that something very much like the filter analogy is occurring in our study, where the bandwidth for detection in the condition NO S π seems wider than that in the condition NO SO. The plateau common to both filters seems to be about 25 cycles in width. This value would represent the width of the peak of the NO SO filter. The occasional reversal of the MLD function at narrow bandwidths indicates that the ears antiphasic filter might have a narrower peak than does the homophasic one.

The shape of the skirts of the two filters now becomes a point of interest. Sue Seitz, in our laboratory, is currently examining the NO SO filter using pulsed tone-on-tone masking.

APPENDIX B

RESPONSE LATENCY AS A CRITERION-DEPENDENT MEASURE

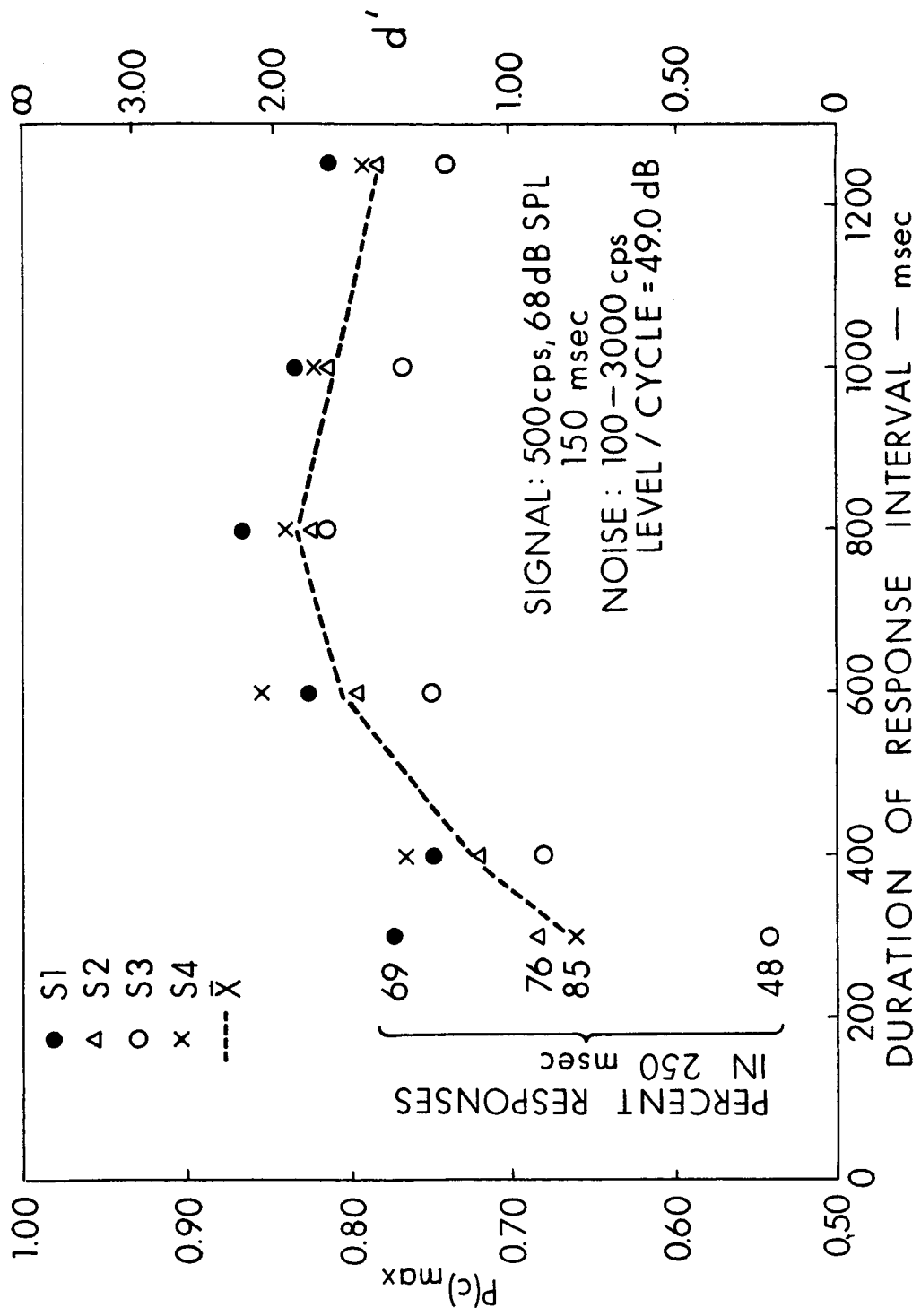
Charles S. Watson
Department of Psychology and Defense Research Laboratory
The University of Texas, Austin, Texas

Early psychophysical studies concentrated a great deal of effort on two aspects of peoples' ability to deal with sensory inputs. The first was the minimal or "threshold"-level of a sensory event required for it to elicit a response and the second the minimal time within which this response could be produced. Reaction-time data have been used for many purposes, from estimation of neural conduction rates to measurement of "cognition time," and recently there has been some discussion of their possible use as indicators of performance in detection tasks. Procedures for measuring reaction times have been quite similar to those used in measuring psychophysical thresholds. When it is found that subjects occasionally respond so rapidly, in comparison with average reaction times, that they may have been jumping the gun, they are warned to be more careful, or to "keep their eagerness within bounds." Woodworth suggests that the basic assumption on which such procedures are based is that there is an irreducible minimum reaction time plus a remainder...the reducible margin, with some more-or-less-random errors distributed around this minimum.¹ As in other areas of psychophysics, evidence has arisen from time to time that could not be easily predicted from such an assumption. Preliminary set has a large effect on reaction time, along with other variables related to the values and costs associated with true and false responses. It is possible that the speed of a reaction to sensory stimuli may be, like readiness to respond at all, a function of some decision rule or criterion adopted by the observer. A simple hypothesis suggests that one may respond early, before all of the "returns are in," at the risk of error, or delay when greater accuracy is required. That is, some decision rule must be adopted which represents the balance between accuracy and speed that the observer is willing to tolerate. The particular rule, or criterion, might be manipulated experimentally to shift the reaction time and the accuracy. Two observers with differing reaction times might thus differ only in their criteria, while being equal in ability to respond rapidly, or they might even be opposite to the original ordering, if compared for a constant level of psychophysical performance.

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I thought that this was such an obvious idea that it must have been looked into, but didn't find that someone had until completing the work I'll show in a moment. W. E. Hick, in 1952,² derived this idea through observing that reaction time was a log function of the amount of information transmitted; that when his subjects transmitted less than the total information in a message they took less time to do it and that the reduced information transmitted could be predicted from the time required to handle a smaller message perfectly.

In a preliminary experiment in visual detection we found, as Hick had, that the great problem in testing the speed-accuracy trading hypothesis is the difficulty in getting observers to do less than perfectly. They prefer to wait and make a perfect decision. A laboratory blunder suggested a simple experimental procedure that might get around this problem. In typical detection experiments we define a response interval, generally about 1200 msec, following the observation interval. If a response is made (pressing the yes or no button) within this interval, a feedback light is flashed indicating to the observer that his response was recorded. The blunder was the missetting of this response time to 600 msec and, as a result, finding that a group of observers was not doing as well as expected in accuracy but were getting all of their responses in the interval. Following this lead we trained a new group to detect a 500 cycle, 68-dB tone, 150 msec in duration, presented in a noise background, 100-3000 cycles in width with a spectral level of approximately 50 dB. We used a yes-no, or single interval procedure, with the signal present on half of the trials and having a three sec intertrial interval and began to collect the data shown in Dwg. No. AS 65-595-S after a week of preliminary training. We started with a 1250-msec response interval and, running four days, or about 2000 trials per subject, for each condition gradually reduced the response interval to 1000, 800, 600, 400, and finally 250 msec. Because of the sequence of these runs we cannot say much about the improvement at 800 msec, except that people haven't found the learning of this task to be such a long term process. It does seem clear that no particular difficulty is encountered when as little as 800 msec is allowed in which to respond. The listeners didn't complain that their response interval had been shortened until we reached 400 msec; with some prodding they were able to get all of their responses in even that interval. At 250 msec they had difficulty in getting all responses in. The average percent



$P(c)_{max}$ AS A FUNCTION OF DURATION OF RESPONSE INTERVAL

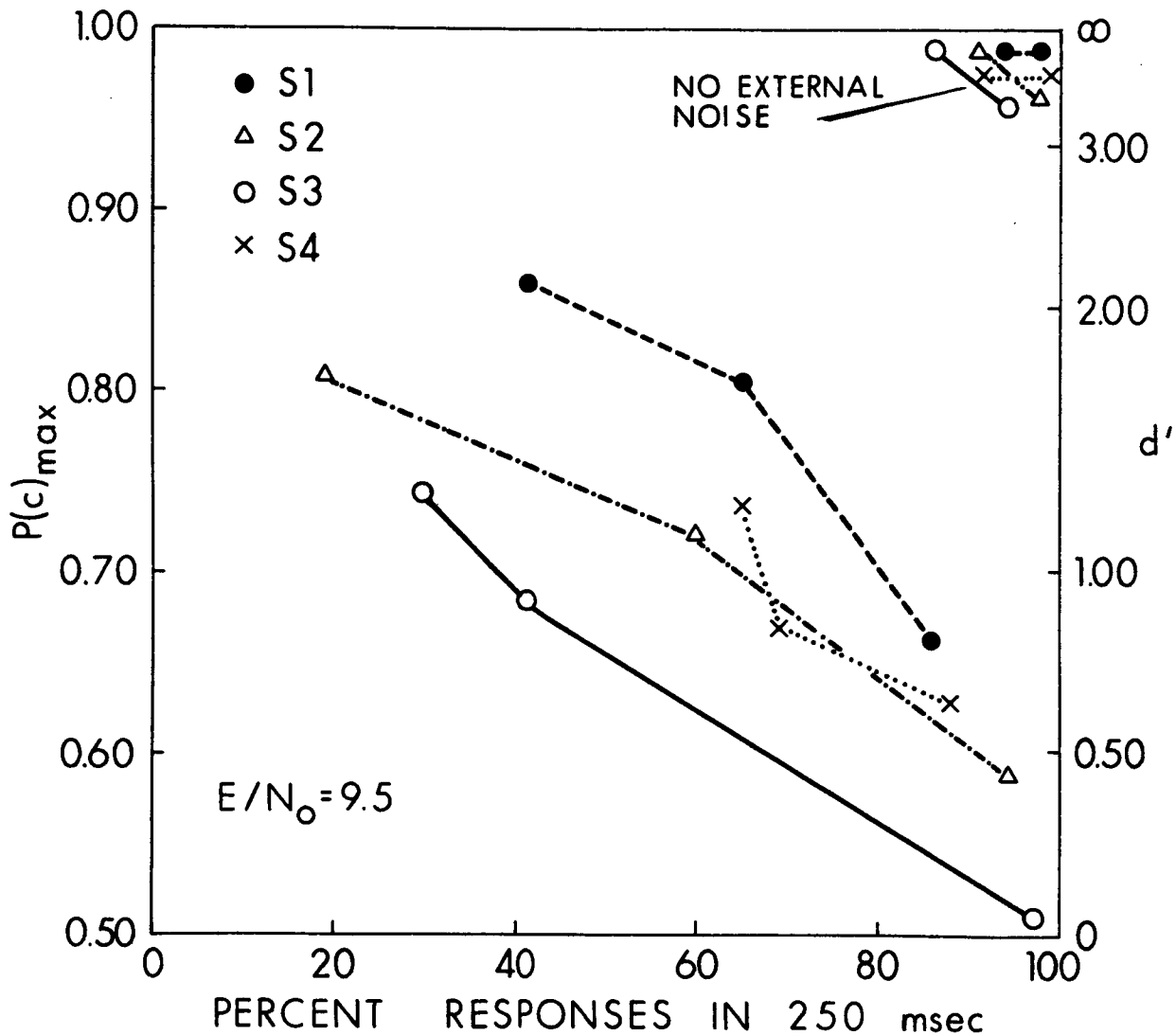
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in the interval varied considerably across the observers, as is indicated to the left of the data points for this interval.

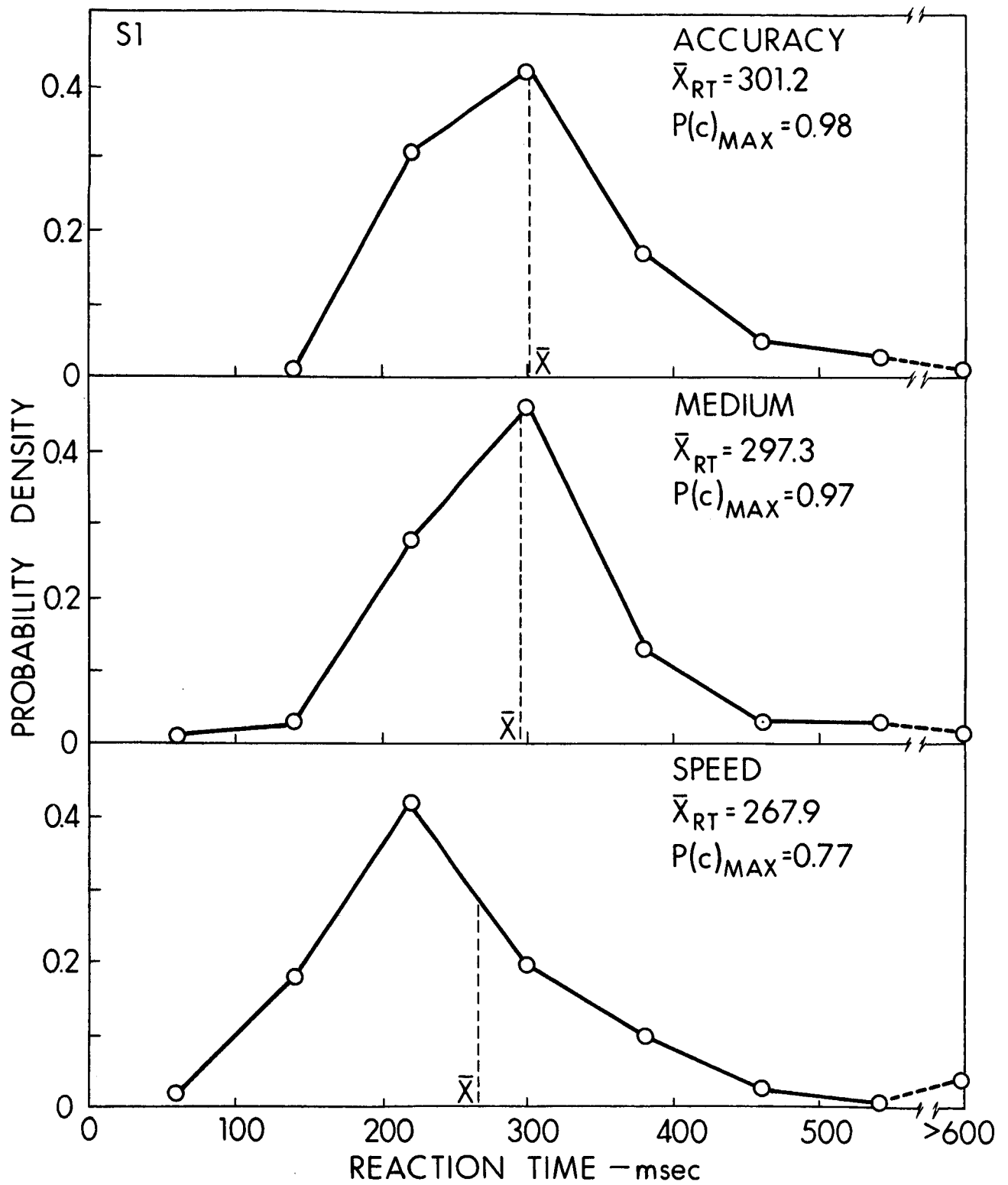
Settling on the 250 msec interval, we next tried varying their speed by instructing them before each block of 100 trials to work either for speed, accuracy, or to be "medium." Speed was always stressed to a considerable extent since the subjects were under the impression that only responses in the interval were counted. Drawing No. AS 65-601-S shows the probability of being correct for all responses, as a function of the percentage falling within the 250 msec interval. $P(C)_{\max}$ on the ordinate is simply the percent correct adjusted for any response bias. The listeners could work from one strategy to another on demand and the trading of speed and accuracy was clear even in data from single blocks of 100 trials. The separation between subjects on these functions is almost perfectly predicted by their differences in ability to detect the signal when 1250 msec were allowed in which to respond, as shown in the previous drawing.

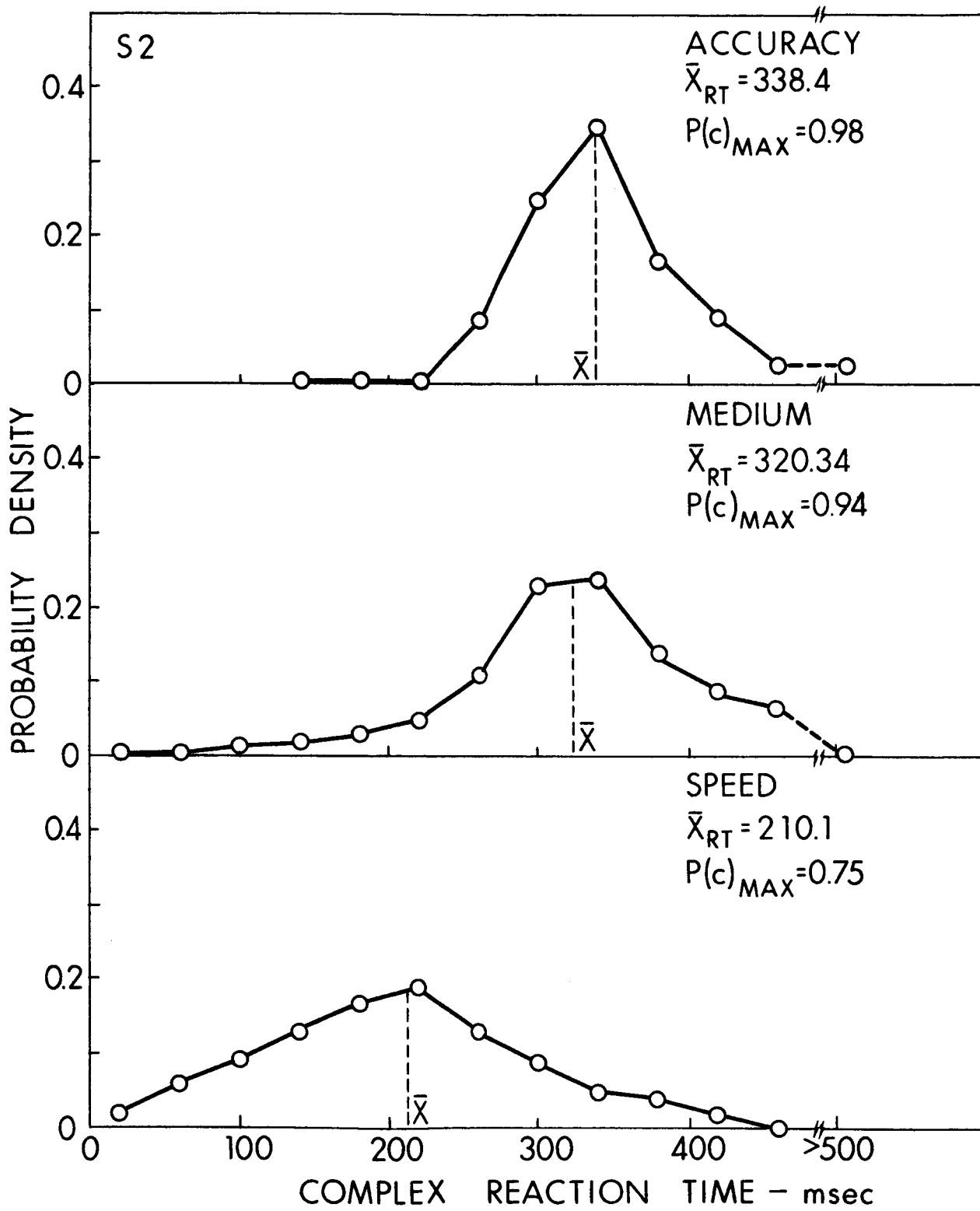
Since some of the variability in these data was apparently a function of the difficulty of the decision, we tried the same instructions for a listening task in which the observers could perform just about perfectly if they took the time, that is, we turned off the noise. The data in the upper right hand corner shows the results. They got almost all of their responses in the interval and were almost 100 percent correct. Shortening the interval to 150 msec, however, produced function very similar to those in the center of the slide, where the decisions were difficult because of the noise.

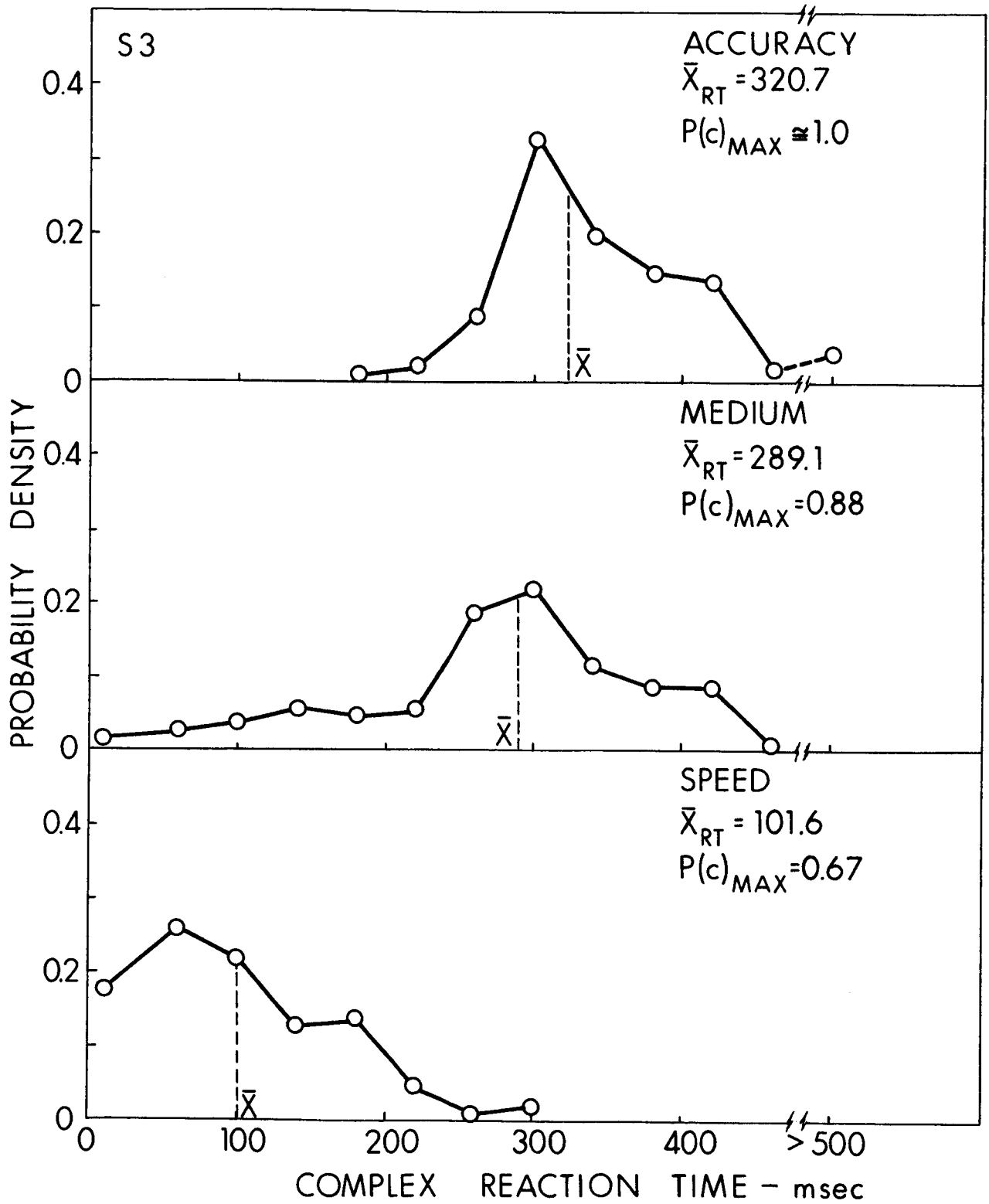
At this point we decided to concentrate on the reaction times rather than numbers of responses in various intervals, and to continue to leave out the noise.. Drawing Nos. AS 65-597-S, AS 65-598-S, AS 65-599-S, and AS 65-600-S show reaction times measured from the onset of the tone to the time of the response. The distributions, from the top, are for the "accuracy," the "medium" and the "speed" instructions. No significant differences in reaction time were found between yes responses and no responses, or between correct and incorrect responses, although we believe these might be picked up under other conditions. The major finding was that the distributions were shifted in the same direction for each subject, although by

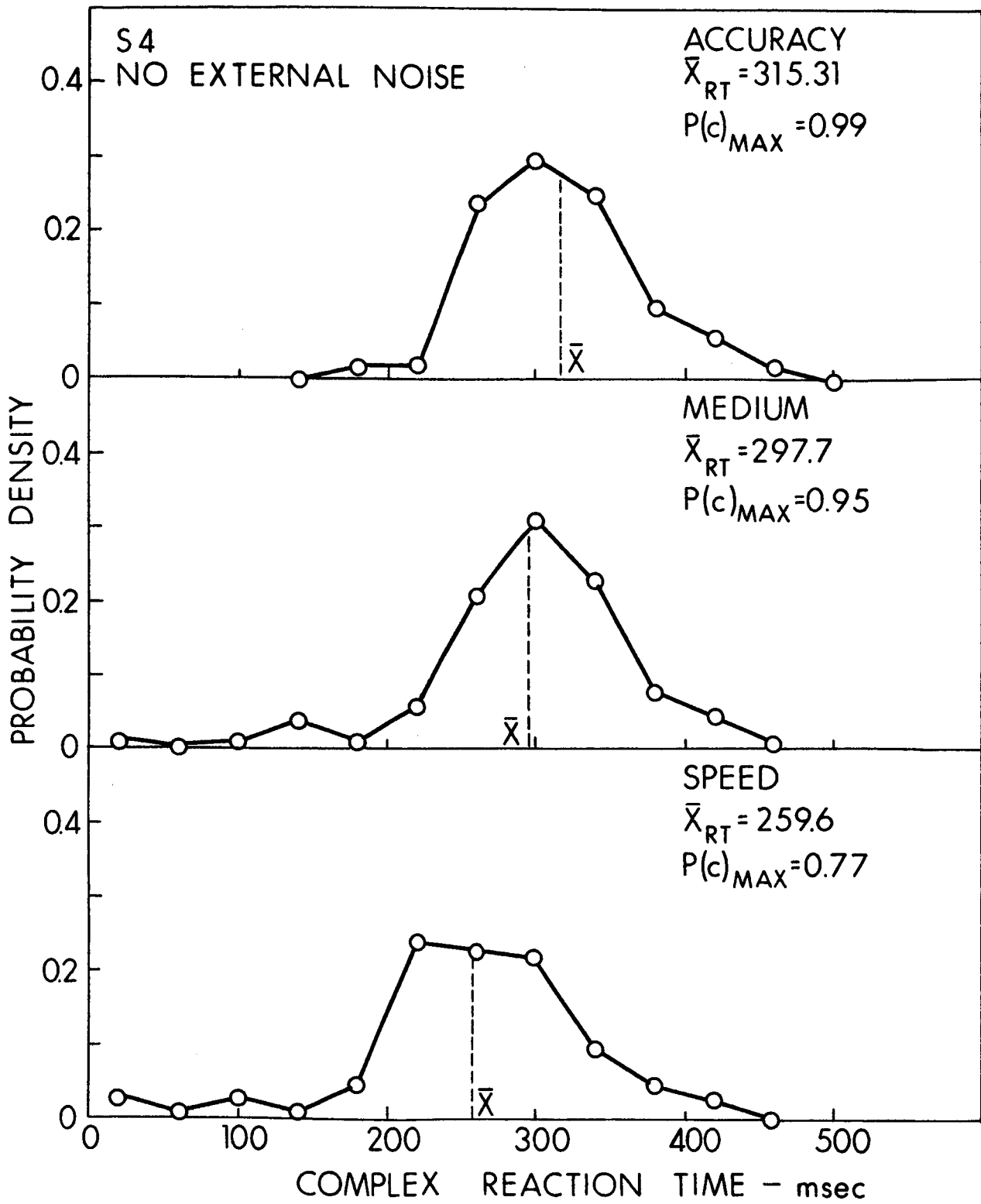


ACCURACY AS A FUNCTION OF PERCENT RESPONSES IN 250 msec RESPONSE INTERVAL









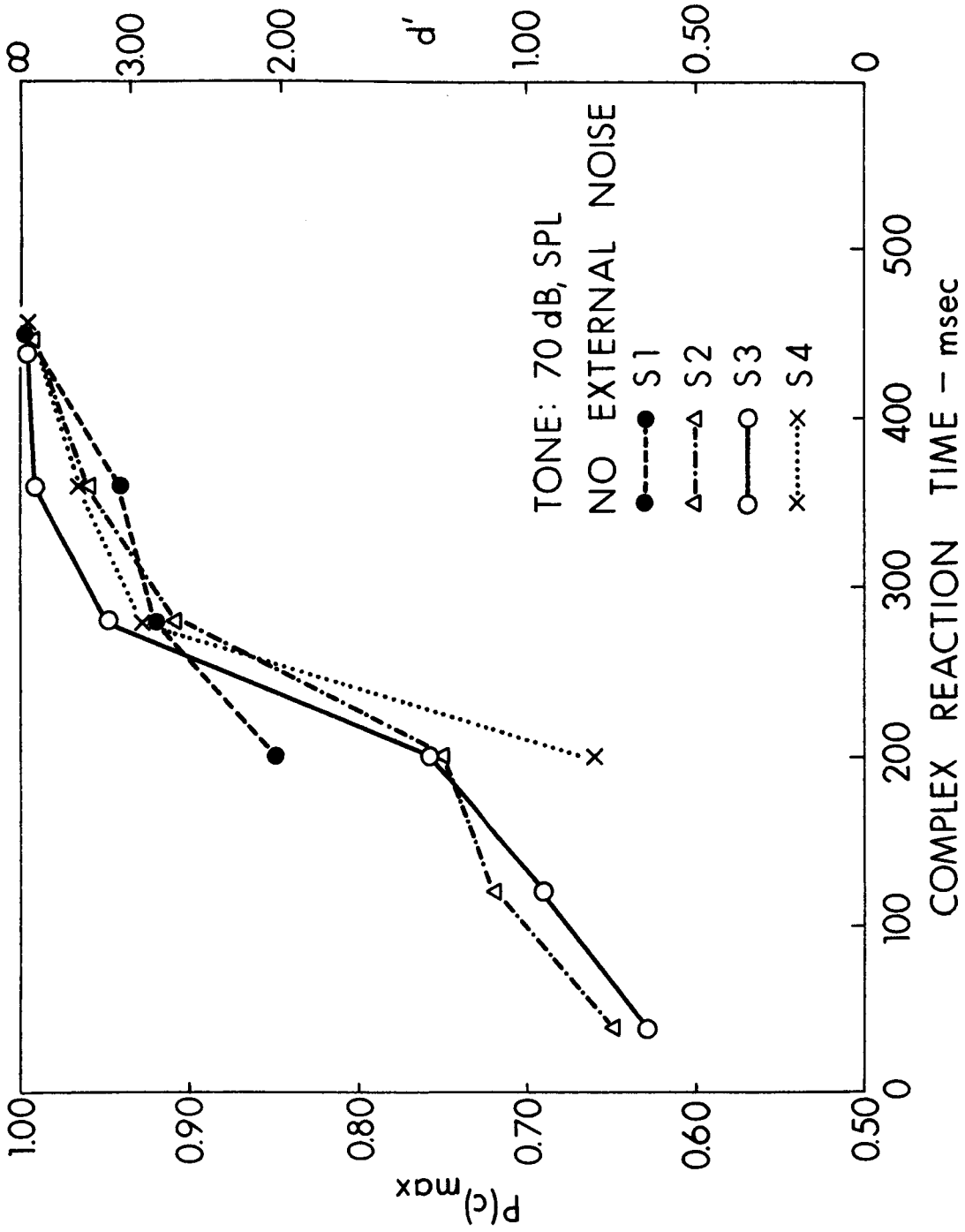
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amounts which were idiosyncratic with the subject. (The subjects appeared to vary in their responsiveness to the instructions.) The regularity of the speed/accuracy trading can be seen in the percent correct and mean reaction time for each distribution.

In Dwg. No. AS 65-596-S the probability of being correct is shown for these same data as a function of reaction time. Without the variance contributed by differences in detection ability the subjects are grouped rather closely together. It is clear that even small differences in acceptable error rates result in sizeable changes in reaction times. For example, moving from 1 percent to 10 percent in error score means a reaction time of 130 msec (from about 400 to about 270).

At this point we speculated that the same trading could be demonstrated in the simple reaction time setting, with signals presented in random time and the observer either responding or not. Jim Egan assured us that it could and reminded us that he observed a related effect in his research on the Method of Free Response.³ He found reaction time increasing as he asked his observers to move from lax to strict in their decision criteria, in addition to the changes in response density.

Finally, if one is interested in reaction time as an index of detectability, there is a more familiar relation between accuracy and speed than the one described here. Many experiments have shown that reaction times increase as decisions become more difficult. Thus, whenever the inputs within a set vary in difficulty (and, if one admits to noisy nervous systems this would probably mean all sets of inputs, at the decision stage) the easier are responded to more rapidly and more accurately if perfect performance has not already been achieved. Two relations that exist between percent correct and reaction time: the one of the present study in which equal inputs are handled more accurately if more time is taken...leading to a positive correlation between percent correct and reaction time and another one, in which reaction time and percent correct are negatively correlated, easy decisions being made more accurately and in less time than hard ones. An observer's range of operation might include both types of effect, but we think the stressing of speed leads to data that can be best described with the speed/accuracy trading relation, while when no stress is placed on response time the observers adopt a strict



ACCURACY AS A FUNCTION OF REACTION TIME

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speed/ accuracy strategy, delaying responses only as they become more difficult. Working without stress on speed Carterette and Friedman have recently shown⁴ that the relation between time to respond and difficulty is regular enough that it may be used to plot ROC curves almost like those obtained from confidence ratings.⁵

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