Semiannual Report, Contract Nonr-3579(04)
1 June 1967 through 30 November 1967
Supported by Fund Transfer R-129 from
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Fourteenth Quarterly Status Report
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Prepared by L. A. Jeffress

L. A. Jeffress
Project Supervisor

Approved by:

C. M. McKinney
Director

DEFENSE RESEARCH LABORATORY
THE UNIVERSITY OF TEXAS AT AUSTIN
AUSTIN, TEXAS 78712

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by

Lloyd A. Jeffress

I. STATUS OF PROPOSED PROBLEMS

A. Detection Performance and Two Parameters of the Auditory Stimulus (T. L. Nichols and Lloyd A. Jeffress)

Work on this project has been completed. A paper covering one aspect of the problem was presented at the November 1967 meeting of the Acoustical Society of America. The data are being prepared for publication, but preparation is suffering some delay owing to the fact that Nichols is in the Army assigned to the U. S. Army Natick Labs, Natick, Massachusetts.

B. Effects of Visual Adaptation on the Detection of a Visual Stimulus (G. H. Jacobs and H. A. Gaylord)

Work on this project has been completed. The findings are being prepared as a doctoral dissertation.

C. Signal Detection and the Width of Critical Bands (R. B. Evan and L. A. Jeffress)

Work on this project is completed and is being prepared for publication.

D. Binaural Models and Psychometric Functions
(P. I. Williams and L. A. Jeffress)

Two binaural models, one based on generating an electrical voltage proportional to the interaural time difference resulting from an antiphasic stimulus, and one based on Durlach's Equalization-Cancellation mathematical model are being run as subjects along with three human observers in a psychophysical experiment. The research will be incorporated in a doctoral dissertation.

E. Monaural Electrical Model
(L. A. Jeffress)

Results of experiments with the electrical model and results of psychophysical experiments with human observers are compared and a mathematical theory of the underlying mechanisms are presented in an article prepared for publication in the Journal of the Acoustical Society of America. A preprint of the article is being sent to the distribution list.

F. Summary of Work Conducted under the Contract
(L. A. Jeffress and G. H. Jacobs)

A summary of major studies conducted under the present contract prepared for presentation at a meeting at Ames Research Center is appended to the present report.

APPENDIX

Work performed under National Aeronautics and Space Administration Grant R-129 to the Defense Research Laboratory of The University of Texas at Austin, Austin, Texas 78712. Grant R-129 is made through the Office of Naval Research Contract Nonr-3579(04).

Visual and Auditory Signal Recognition

The work on the projects to be reported was supported by the National Aeronautics and Space Administration through a grant to the Defense Research Laboratory of The University of Texas at Austin (Grant R-129). The work received additional support from the Naval Ship Systems Command Contract NObsr-93124. The work on vision was conducted by Dr. Gerald H. Jacobs and his graduate students, and the work on audition by Dr. Lloyd A. Jeffress and his graduate students. Both are members of the Psychology Department of The University of Texas at Austin.

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Visual Research

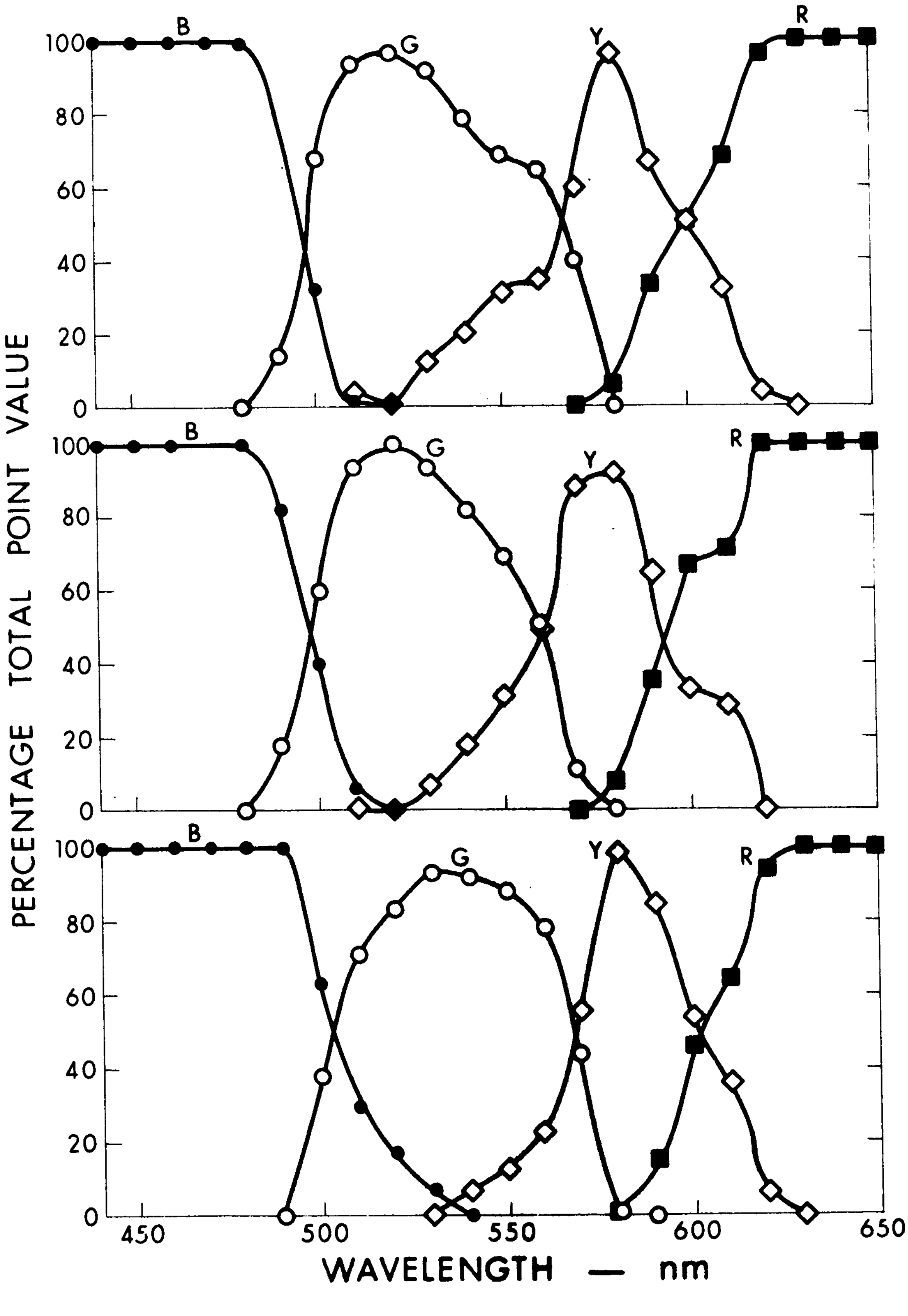
Effects of Chromatic Adaptation on Color Naming

The four color names, Blue, Green, Yellow, and Red were employed singly or in pairs by the subjects in identifying the color presented to them after a period of chromatic adaptation. The responses were scaled as follows: Blue was graded 3; Blue-Green was scaled 2 for blue and 1 for green; Green-Blue was scaled 2 for green and 1 for blue, etc. There was a possible total of 72 points for each test wavelength. The graphs show the percentage of total points assigned to each wavelength indicated on the abscissa. AS-66-739 is the results for three subjects after 5 min of initial neutral adaptation at 195 ft L. The test stimuli were of the same luminance and were presented for 300 msec at 18 sec intervals, alternating with the adaptation light which was on between test trials. The stimuli were presented in Maxwellian view subtending 40 deg.

Drawing No. AS-66-740 shows the results after adaptation with a W 92 filter (646 nm). It will be seen that the red has almost disappeared, the yellow is shifted well toward the red, the green has been extended over a wide range of wavelengths and the blue is virtually unaffected.

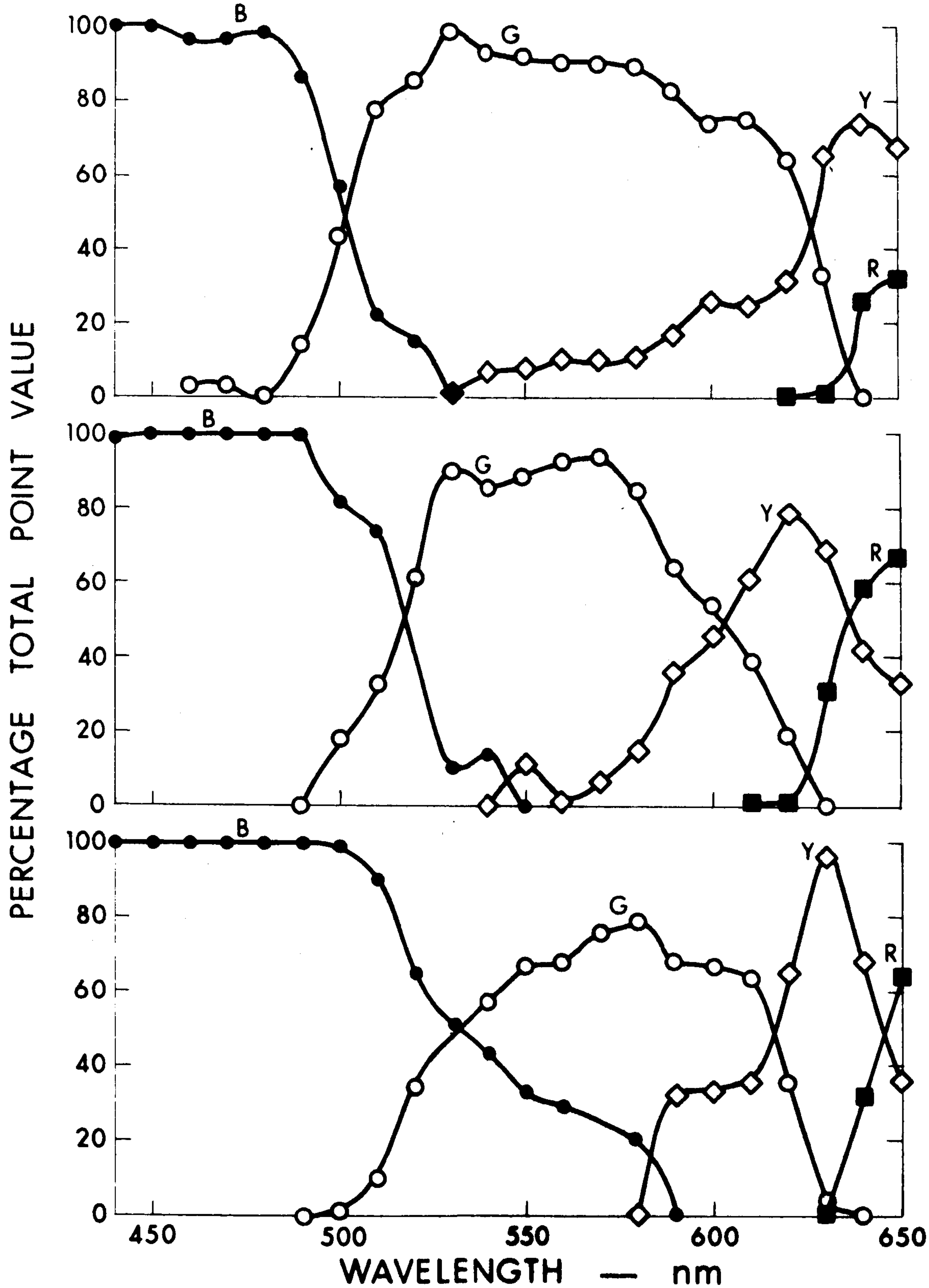
Drawing No. AS-66-741 shows the effect after adaptation with a W 98 filter (452 nm). Here the blue has been greatly restricted and moved to the left. The red has been shifted to the left and even appears in the blue region as red-blue or blue-red. The extent of the green has been greatly reduced, and shifted to the left, and the area of yellow has been increased and shifted to the left.

Drawing No. AS-66-742 shows the effect of adaptation with a W 74 filter (538 nm). Here the red and blue have been expanded toward



COLOR NAMING NEUTRAL ADAPTATION

DRL - UT
DWG AS-66-739
GHJ - DCC
8 - 9 - 66



COLOR NAMING W 92 ADAPTATION

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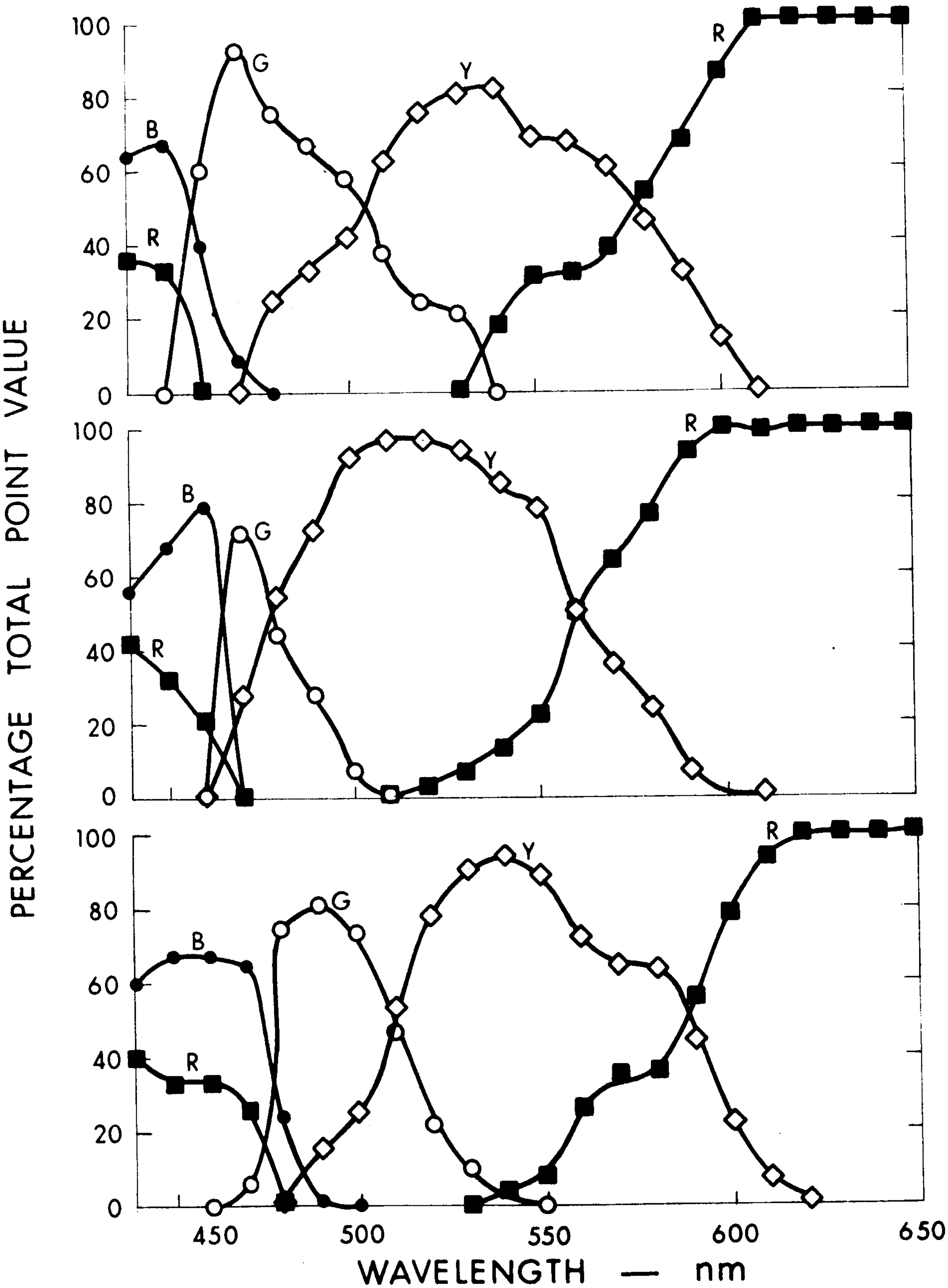
GHJ - DCC
8 - 10 - 66



COLOR NAMING W 98 ADAPTATION

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GHJ - DCC
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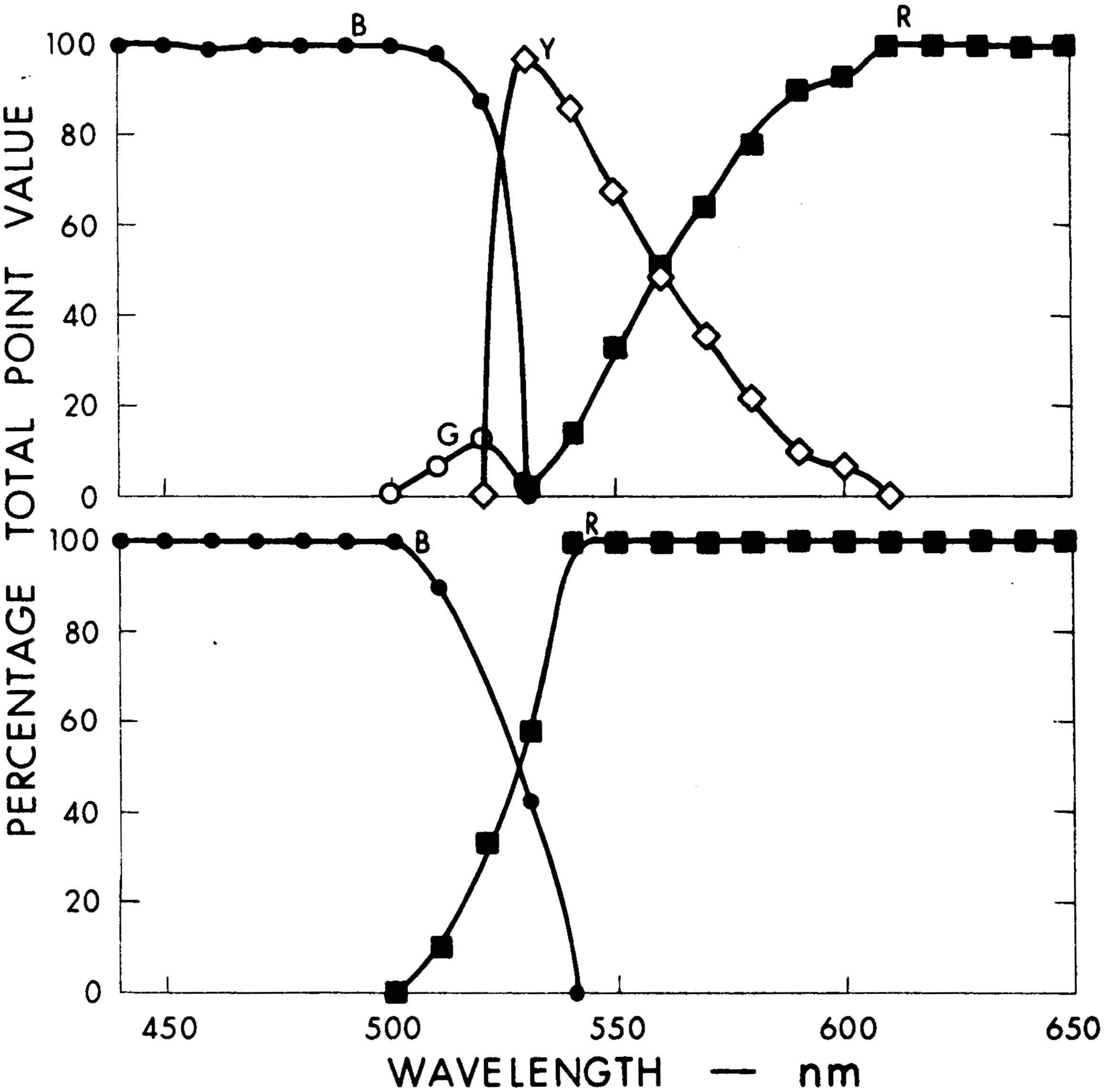


COLOR NAMING W 74 ADAPTATION

DRL - UT
DWG AS-66-742
GHJ - DCC
8 - 11 - 66

the middle, and the green and yellow responses completely suppressed for one subject and greatly restricted for the other.

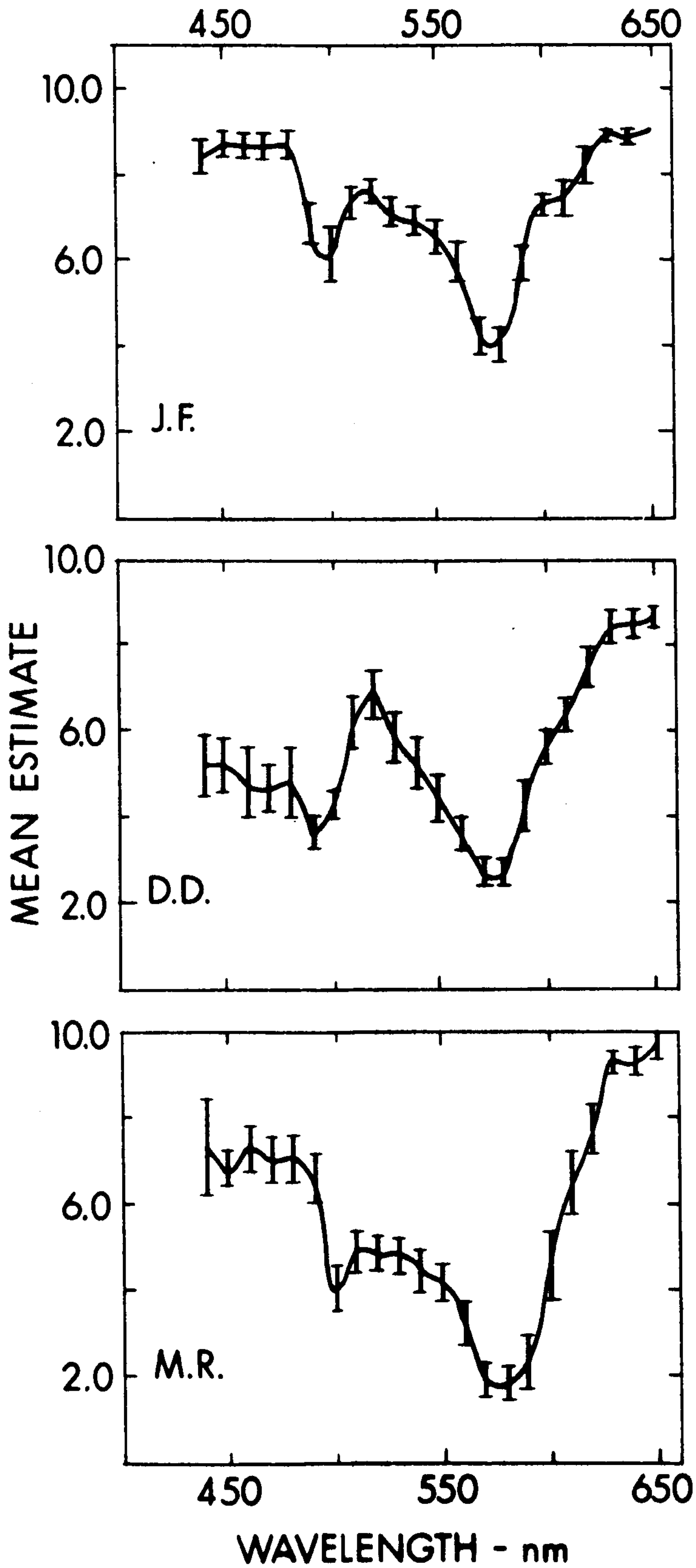
The results, in addition to indicating the effect on hue of prior adaptation, illustrate the effectiveness of color naming as a quantitative experimental research procedure. Split-half reliability correlations for the data were mostly in the high 90's, and the method is much less time consuming than matching procedures.

One practical suggestion from the results has to do with the use of colored light in the illumination of sonar and radar spaces. The red commonly employed on board ship to preserve dark adaptation is about the most inappropriate lighting for spaces where the color to be detected is the greenish yellow of many scope phosphors. Neutral light, or blue, would be much better.

Saturation Estimates and Chromatic Adaptation

In addition to being able to assign color names reliably, subjects prove to be able to estimate the saturation of colors presented after various types of adaptation. The subjects were instructed to assign numbers ranging from zero to ten to the saturation of test colors presented after adaptation. AS-66-1341 shows data for three subjects after neutral adaptation for 5 minutes. (Maxwellian view, 40 deg, same procedure as in the previous experiment.) The bars indicate one standard deviation above and below the mean estimate.

Drawing No. AS-66-1342 shows the effect of adaptation to a long wavelength (W 92, 636 nm). It will be seen that saturation estimates for the long wavelengths have been greatly reduced. AS-66-1343 shows the effect of adaptation to a short wavelength (W 98, 452 nm). Here there is a marked reduction in saturation for wavelengths from medium to short, with increased saturation for wavelengths at the other end



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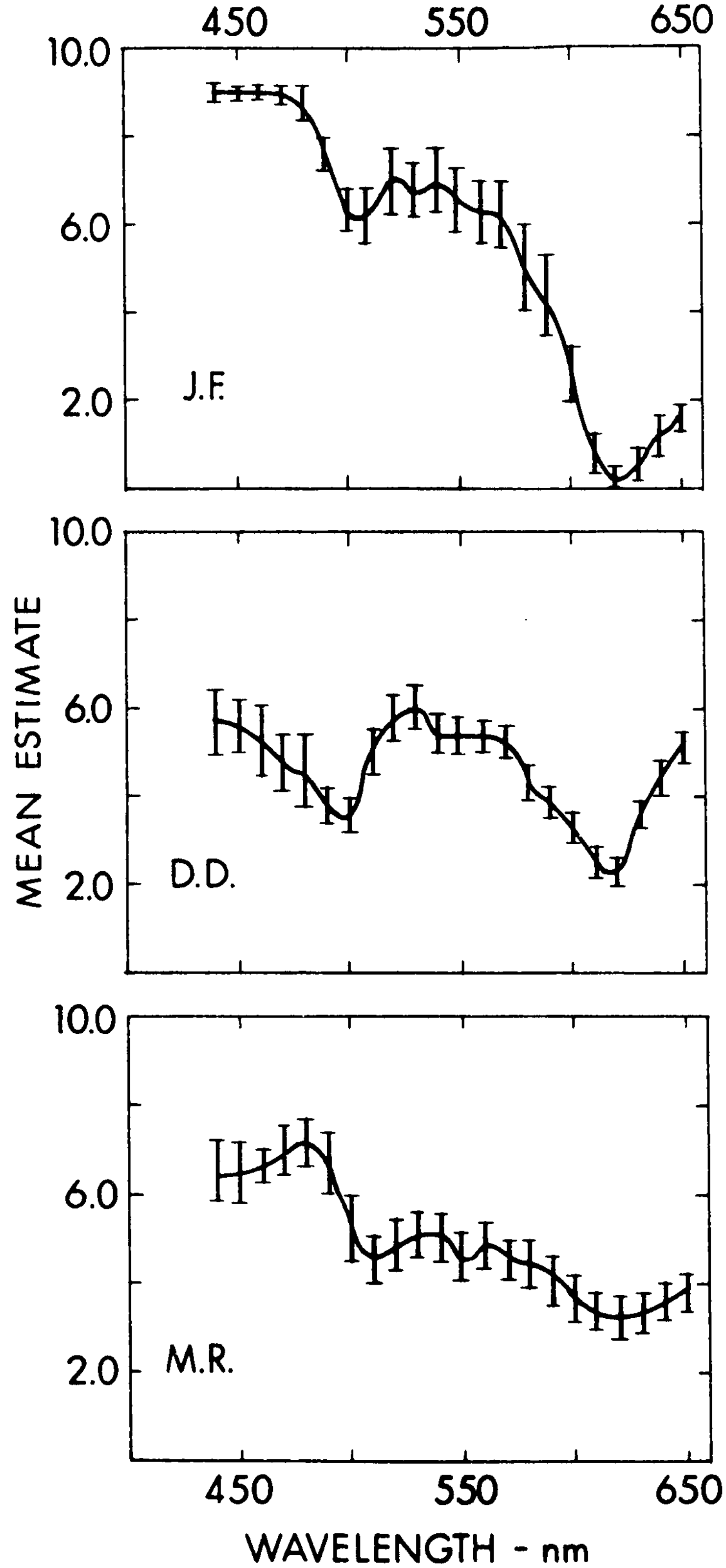
GHJ - ORS
1 - 24 - 67

SATURATION NEUTRAL ADAPTATION



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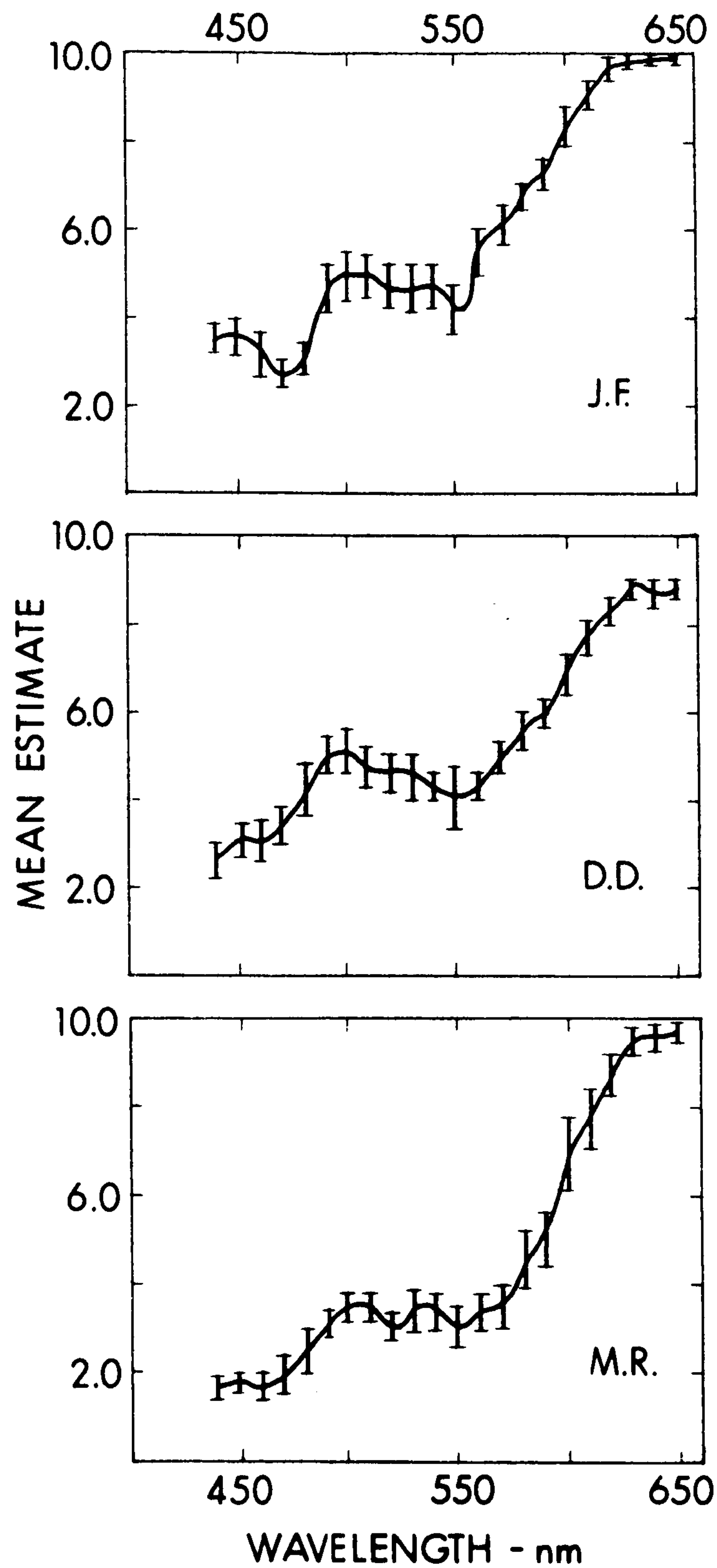
GHJ - ORS
1 - 25 - 67

SATURATION W 92 ADAPTATION



DRL - UT
DWG AS-66-1343
GHJ - ORS
1 - 26 - 67

SATURATION W 98 ADAPTATION

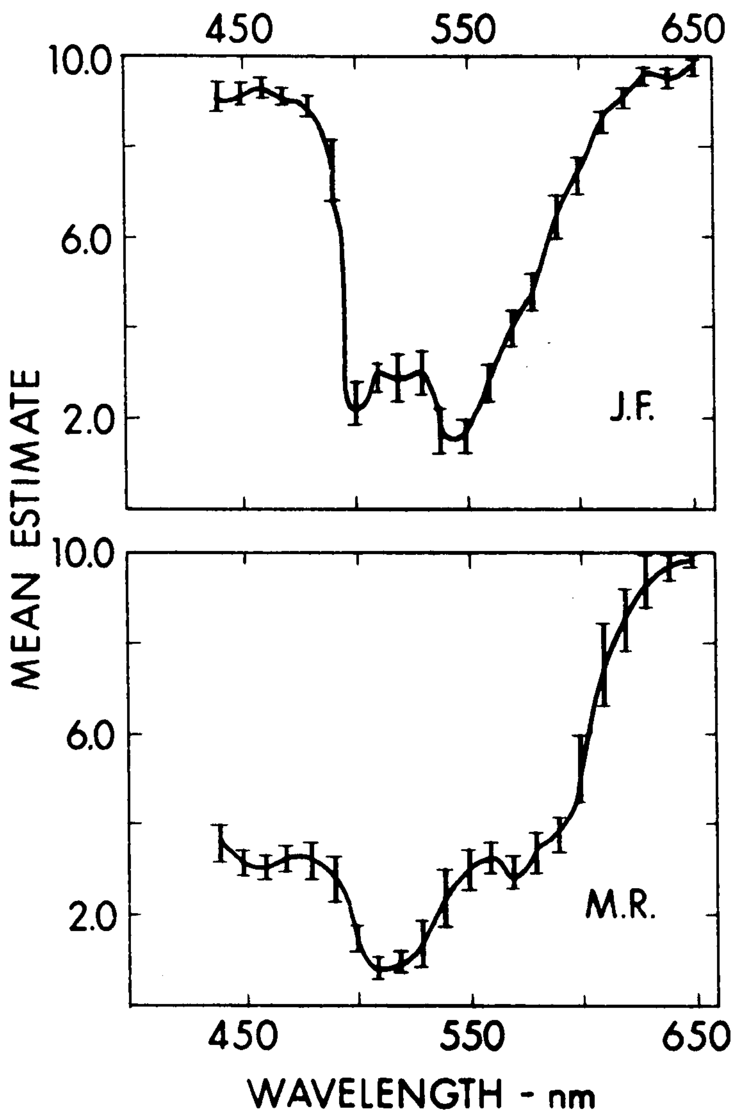
of the scale. AS-66-1344 shows the effect of adaptation for green (W 74, 532 nm). Here there is depression of the estimates in the middle, with a considerable increase in the estimates for the long wavelengths, and for one subject, for the short as well. The relatively small spread for any particular wavelength indicates that the judgments are being made with good consistency.

Effects of Adaptation on Visual Detection

It is frequently suggested in recent literature, following Barlow (1964), that the effect on the retina of exposing it to light is to make its behavior in subsequent darkness "noisy". This implies that the detection of a weak visual "signal" in the dark following a brief flash of adaptation light is essentially the detection of a signal in noise. For this, and a number of other reasons, the present experiment was undertaken as a detection task. A rating-scale procedure was employed to permit the construction of receiver operating characteristic (ROC) curves from the subjects' responses.

The adaptation light and the signal were presented in Maxwellian view. The former subtended an angle of 25 deg, and the latter, 5 deg, in the center of the adaptation field. The exposure of the adaptation light was controlled by a mechanical shutter which allowed it to be presented for 200 msec. The retinal illuminance provided by the adaptation light was 6.74 log trolands. The test light (signal) was a glow-modulator tube which was flashed electronically for 20 msec at a constant illuminance level (constant spectrum), and attenuated by a series of neutral filters 0.1 log units apart, ranging from 2.04 to 0.54 log trolands of retinal illuminance. A bite-board and a dim red "grain of wheat" fixation light served to maintain the desired orientation of the eye.

After spending a minimum of ten minutes in a dimly lighted room, the subject entered the dark test booth. After 2 minutes of dark

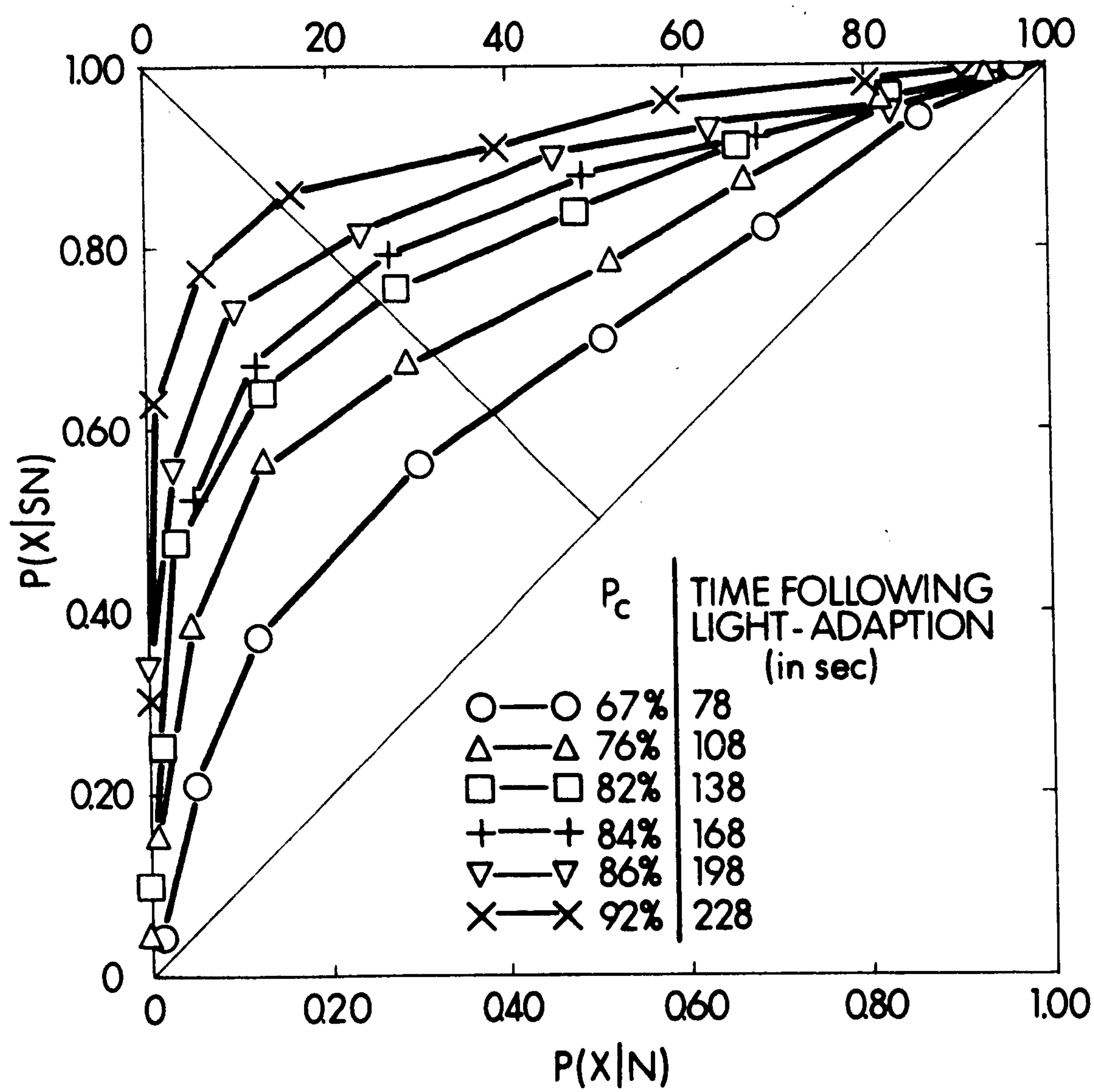


SATURATION W 74 ADAPTATION

DRL - UT
DWG AS-66-1344
GHJ - ORS
1 - 26 - 67

adaptation, the fixation light was turned on, and S signaled by means of a push button that he was ready. The adaptation light was then turned on for 200 msec, and every 6 seconds following the termination of the adaptation light a 1 sec warning tone was presented. At the termination of the tone, the test signal was either turned on or not (with an a priori probability of 0.5). The subject responded with an appropriate push button to indicate his assurance that a signal had or had not been presented. A response of "1" represented virtual certainty that there had been no signal, and "10", virtual certainty that there had been a signal. Forty such 6 sec periods following the adaptation flash constituted one "run", and from five to ten such runs separated by 2 minutes of dark adaptation constituted an experimental session. The luminance of the test signal was varied during the run and from one run to another according to a planned-haphazard program so that any of six or seven illuminances might occur during any trial in the run of 40. The values were chosen so that the percentage of correct responses at any period following the adaptation flash fell within a reasonable range for getting ROC curves. Some 400 ROC curves were obtained during the course of the study and the values of P(c) were determined from their area as measured by a planimeter. AS-67-1661 shows a family of ROC curves for the average of the three subjects. The data for this drawing were taken at a test-light illuminance of 0.54 log trolands. The parameter of the family of curves is the time following the adaptation flash at which the data were taken.

Drawing No. AS-67-1718 shows the course of dark adaptation. The abscissa is time after the adaptation flash, and the ordinate is the illuminance needed to reach the percentage correct indicated as the parameter of the family of curves. This drawing is for a single subject. The other drawing showed similar results. The subjects were asked to report the moment when the positive after-image of the adaptation light disappeared. This occurred about



ROC CURVES FOR 0.54 LOG TROLAND "SIGNAL"

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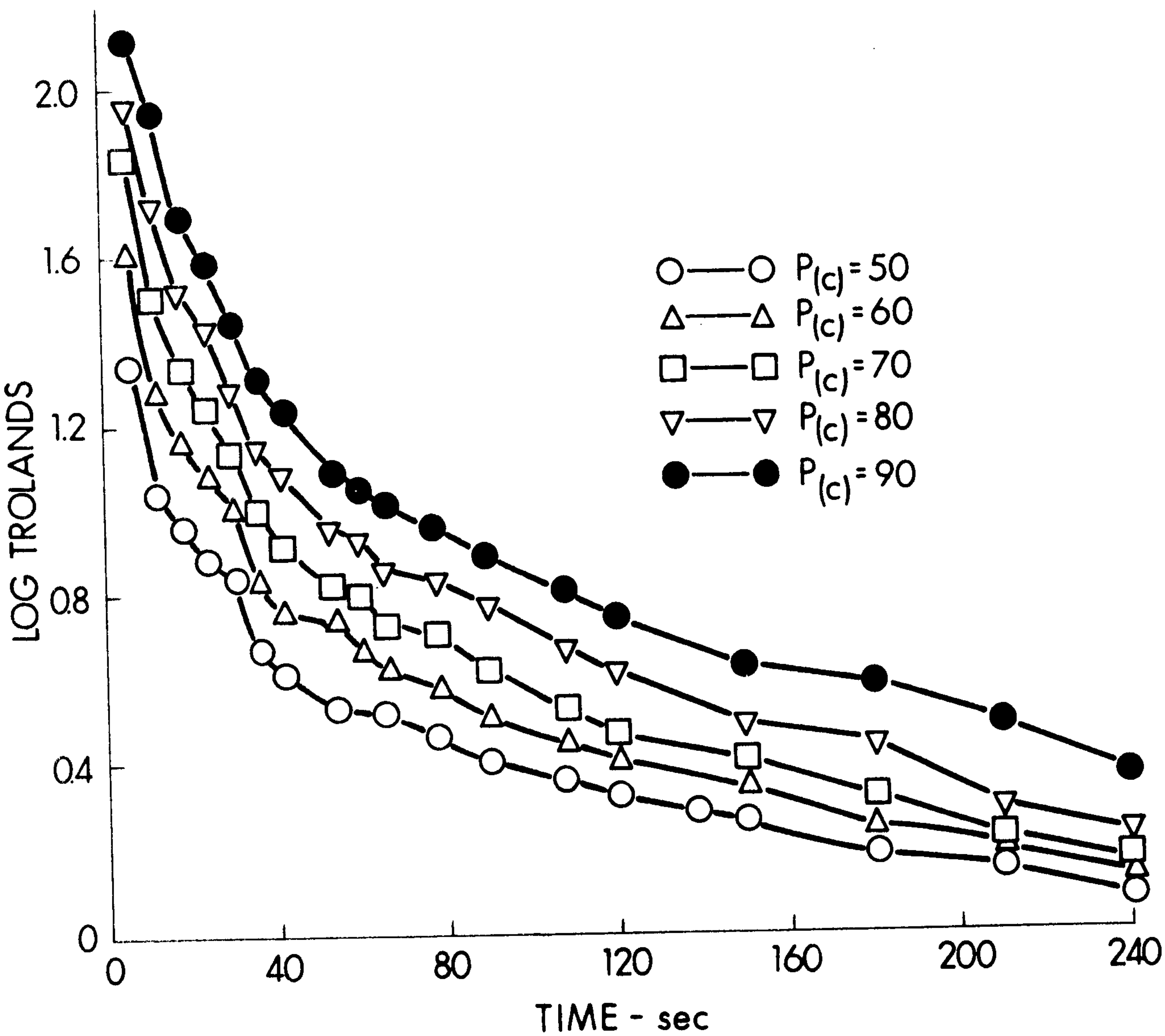
AS-67-1661-S
LAJ - ORS
12 - 21 - 67



COURSE OF DARK ADAPTATION FOR ONE SUBJECT

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AS-67-1718-S
LAJ - ORS
12 - 21 - 67

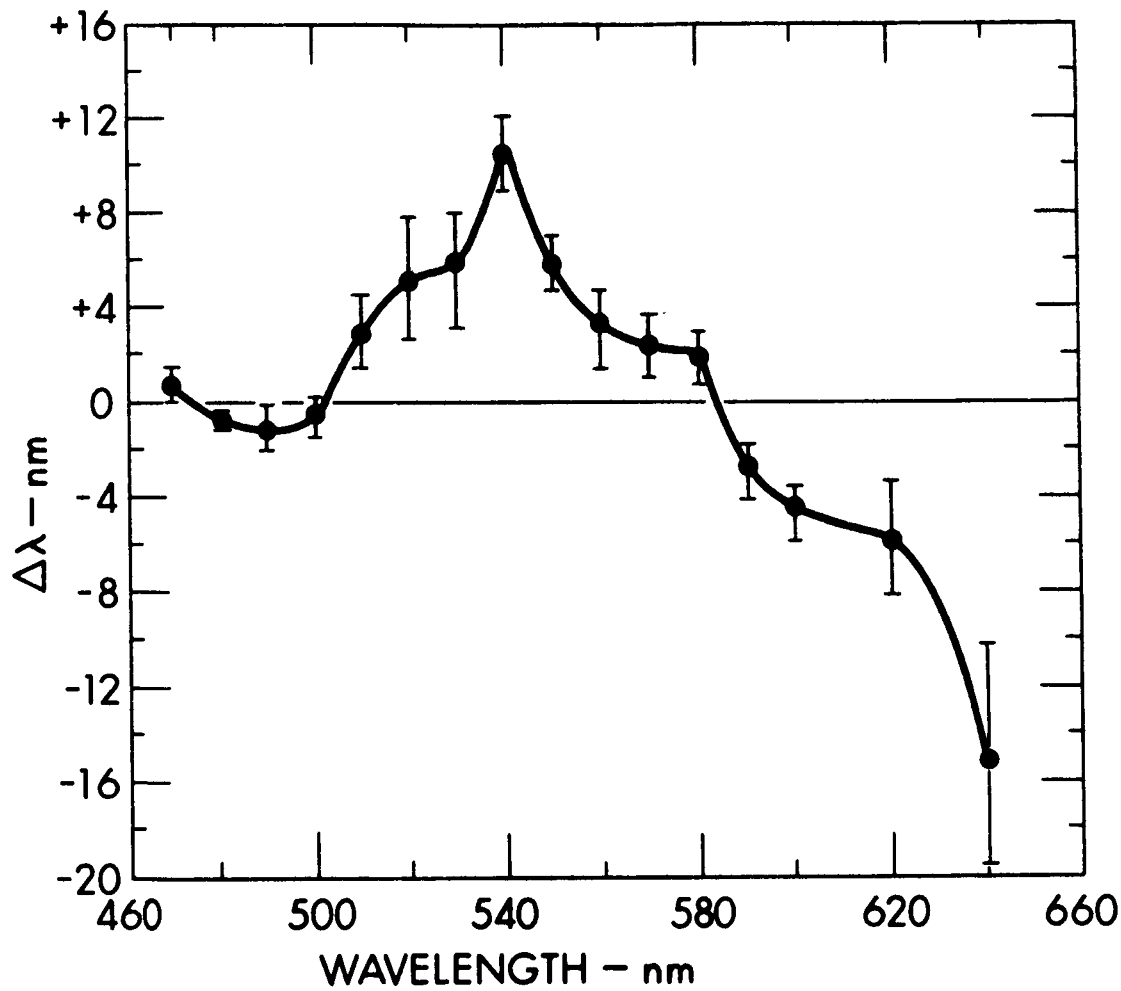
2 minutes after the exposure, but was not accompanied by any discontinuity in the recovery curve. The retinal "noise" is apparently not dependent on the presence of the positive after-image.

This study is forming the basis for a doctoral dissertation by Mr. Heinz Gaylord.

The Bezold-Brücke Hue Shift

In spite of the importance of the Bezold-Brücke shift to theories of vision, much of our knowledge of the phenomenon is based on a single study by Purdy, made over 30 years ago and on a single subject. It therefore seemed appropriate to examine the effect with a substantial population. Seventy-two subjects, 33 females and 30 males, were employed in the present study. The color-naming procedure described earlier was used. The apparatus was a two-beam device with one beam providing the low-level adaptation light, the other, the test wavelength. Measurements were made in the range from 470-630 nm, using a grating monochromator adjusted to yield a passband of 15 nm. Two luminance levels, 320 and 3200 trolands, were used with central fixation in Maxwellian view subtending an angle of 3 deg. Test stimuli were presented for 300 msec once every 18 sec. The adaptation light was viewed during the times between test stimuli. The order of stimulus presentation was randomized and every subject given several practice stimuli before data collection was undertaken. Each subject served for one hour and received as many stimuli as could be programmed in that time.

The color-naming values were converted into nm's of shift and are presented in AS-67-416. The plotted points are the means for the sample of observers tested, and the bars represent 2 standard errors of the mean for the point. In general, the shifts shown here are smaller than those reported by Purdy, but the so-called invariant



BEZOLD BRÜCKE HUE SHIFT

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DWG AS-67-416
GHJ - RFO
4 - 12 - 67

points occur at 584, 502, and 474 nm for the mean of the present sample--about the same locations as found in earlier studies.

The variability shown in the figure probably is largely the result of individual differences, since an earlier study shows that the method is capable of a high degree of reliability.

It was also possible to determine from the data the spectral location of unique yellow and unique green at the two luminances employed. The location of the unique yellow did not change systematically. The mean was 580.55 nm under the low-luminance condition and 580.50 nm for the high. However the location of the unique green showed an interesting effect. Table I shows the finding.

Table I

Unique green loci (in nm) for two classes of observers at two luminance levels. Results of statistical evaluations of row and column differences are indicated.

	N	Low luminance	High luminance	
Type I	19	513.1	509.9	$p < 0.05$
Type II	11	525.5	511.0	$p < 0.01$
		$p < 0.01$	$p > 0.05$	

It will be seen that the subjects appear to fall into two groups in their location of unique green at a low luminance level. The difference disappears at the high luminance level. Both groups show a shift in the location of the unique green at the low level, but the shift for group II is much greater than for group I.

In addition to the psychophysical work just reported, Dr. Jacobs and his students are conducting behavioral and neurophysiological studies on animals, with additional support from the National Science Foundation (Grant GB 4150 26-1007-2950). This work involves both color and spatial sensitivity of single units of the lateral geniculate. The findings of the work on color sensitivity are shown to correlate highly with the behavior of the animals in discrimination tasks.

Auditory Research

Beginning in May 1964, the National Aeronautics and Space Administration through Grant R-129 provided support for work in audition that was already receiving support from the U. S. Navy Bureau of Ships through Contract NObsr-72627. The addition allowed us to increase our effort in this field and to provide assistance for more graduate students--both experimenters working on dissertation problems and subjects who received hourly pay for their services. The grant also made it possible for us to construct considerably more flexible programming and recording equipment. At the present time most of our data are recorded on punched cards which are then analyzed by the Laboratory's CDC 3200 computer. Four subjects at a time can be run in psychophysical studies. Several signal levels can be employed in a single session and single interval, two-interval forced choice can be employed; or rating-scale responses can be recorded. Serial effects can be examined where desired, and multiple observer responses as well.

Most of our recent work in audition has been concerned with detecting a signal in noise, although earlier a considerable amount of research was devoted to various problems in the localization of sound. The masking studies have fallen into two main categories, those concerned with the detection performance of the single ear, and those concerned with the binaural release from masking which can occur when stimuli to the two ears are not identical.

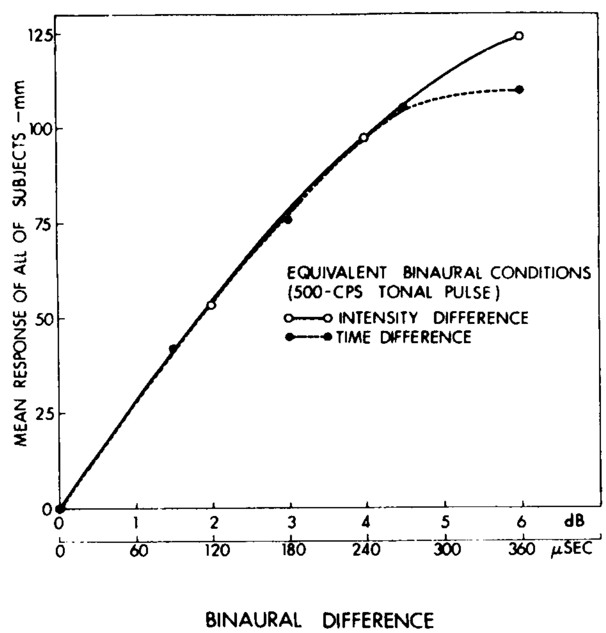
Binaural Studies

Time and Intensity Differences and Lateralization

This was a study conducted by a summer Science-Participation high school student (Brant T. Mittler) under National Science Foundation support, and supervised by Dr. Charles S. Watson. The student and his subjects were 17-year-olds. The subject's task consisted of drawing lines across a sketch of the head to indicate the range of movement of a commutated sound. The sound, a 500 Hz tone, was presented via earphones with either a level difference or a phase difference between the inputs to the phones. The inputs were commutated at half-second intervals and produced a distinct impression of movement within the head. The locations of the ends of the lines represented the point at which the subject thought movement began and ended. The data sheet was located behind a slit in a sketch of a face and moved between trials so that each judgment could be made without reference to previous ones. The following drawing shows the mean length of line associated with the intensity difference or the time difference shown on the abscissa. It will be seen that the "trading ratio" obtained in this way is in good agreement with others in the literature: about 60 μsec per dB.

Masking-Level Differences for Tone and Narrow-Band Noise

A 50 Hz wide band of noise centered at 500 Hz, and a 500 Hz tone were employed as signals in a binaural masking experiment. Webster



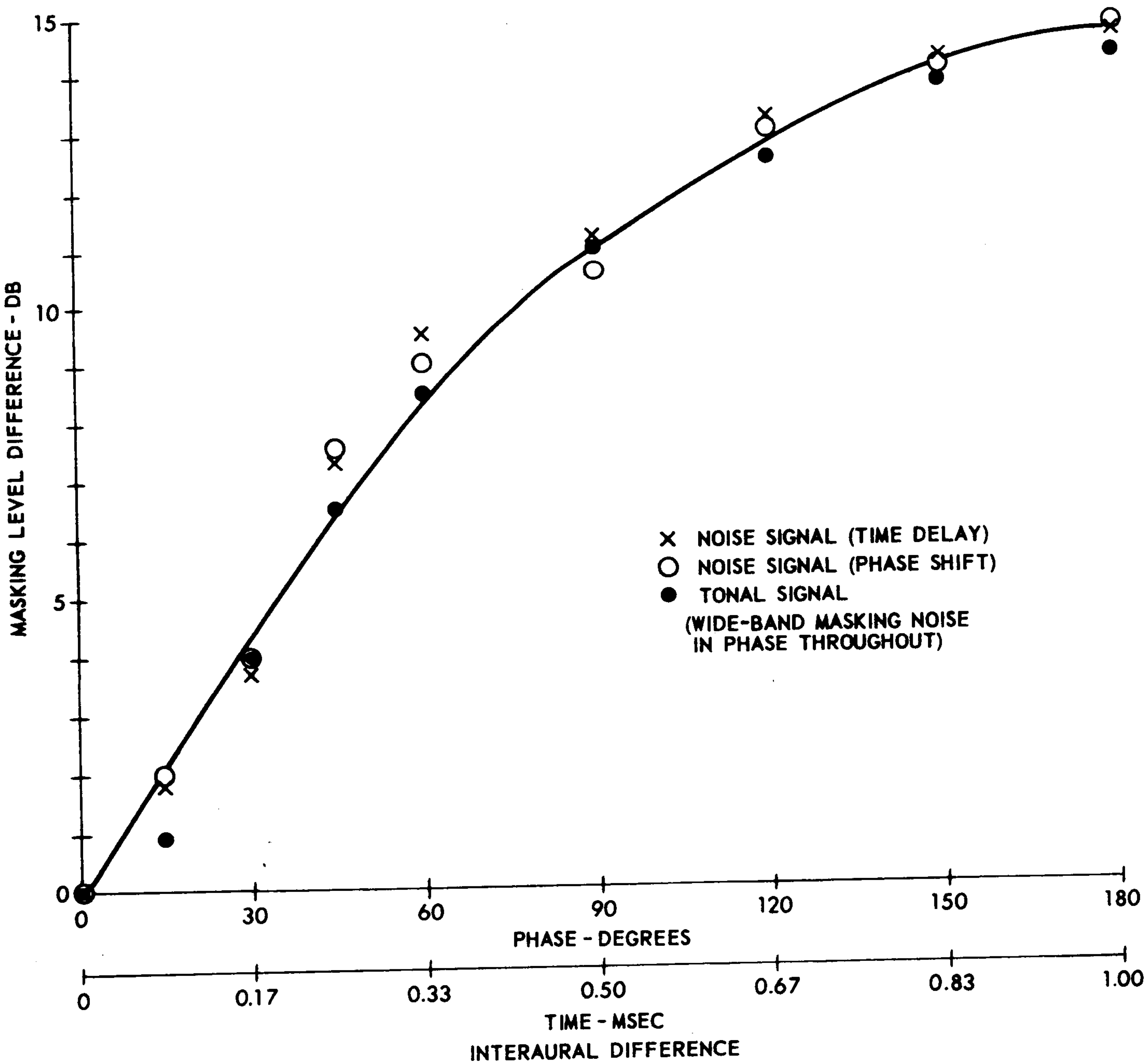
Equivalent binaural time- and intensity-differences, plotted by adjusting the abscissas to make the two functions coincident. This adjustment emphasizes the similarity in subjective effect of 60 μsec. and 1.0 db in shifting a sound image off of the median plane.

LENGTH OF LATERAL MOVEMENT OF A SOUND

and Hirsh had reported much larger masking-level difference for a noise signal than for tone. The present experiment was undertaken in part to check their findings, for which no theoretical explanation was apparent. The major results are presented in AS-9174. It will be seen that there is no significant difference between the MLD's for noise and tone, and that it makes little difference whether the noise is shifted in time, by a delay line, or in phase by a phase shifter. A second experiment to attempt to explain the findings of Hirsh and Webster revealed that they had employed the same noise generator for their masker as for their signal. When these conditions were replicated, our findings agreed with theirs. A large MLD (18 dB) was obtained when the masker and signal were in phase opposition. It occurred, however, because of the considerable increase in the signal needed in the NO SO reference condition, not because of any great release from masking under the antiphasic condition.

Binaural Detection as a Function of the Bandwidth of the Masking Noise

Earlier work had suggested that the bandwidth involved in binaural detection is somewhat wider than that for monaural detection. The present experiment was undertaken to study this possibility. Equivalent rectangular bandwidths of 2900, 508, 422, 303, 185, 160, 130, 109, 50, 22, and 12.6 Hz were employed for the masker. The signal was a 500 Hz tone of 150 msec duration and a rise-fall time of 25 msec. Three levels of noise were employed: 50, 45, and 30 dB spectral level. A low-level wide-band background noise was used to mask the second harmonic of the signal, that was about 60 dB below the fundamental. The stimuli were presented either with both noise and signal in phase at the two ears, NO SO, or with the signal reversed in interaural phase, NO Sπ. AS-65-816 shows the results for one subject for the diotic condition NO SO. It will be seen that the



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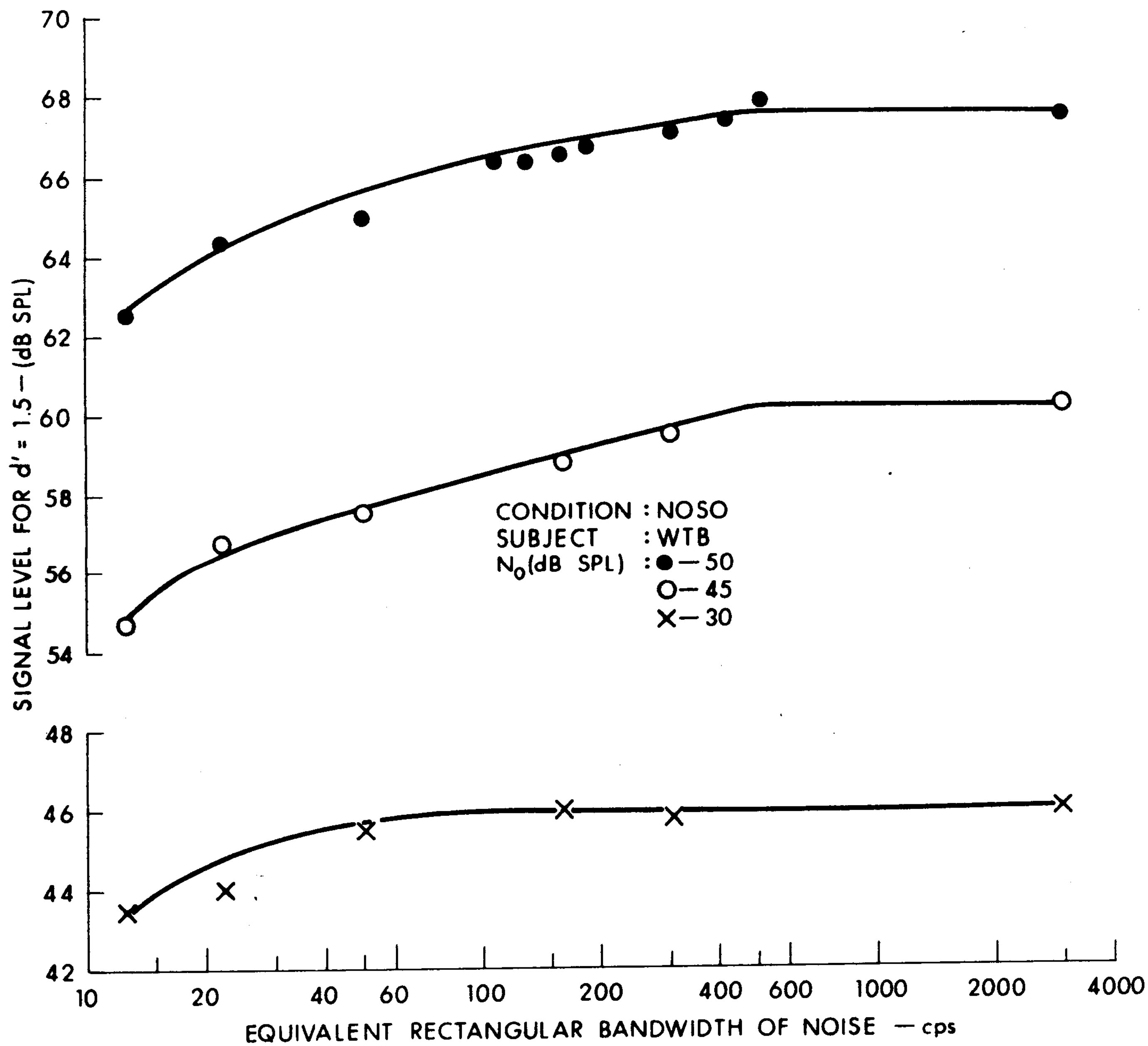
MLDs FOR TONE AND NARROW-BAND NOISE



EFFECT OF BANDWIDTH ON HOMOPHASIC DETECTION

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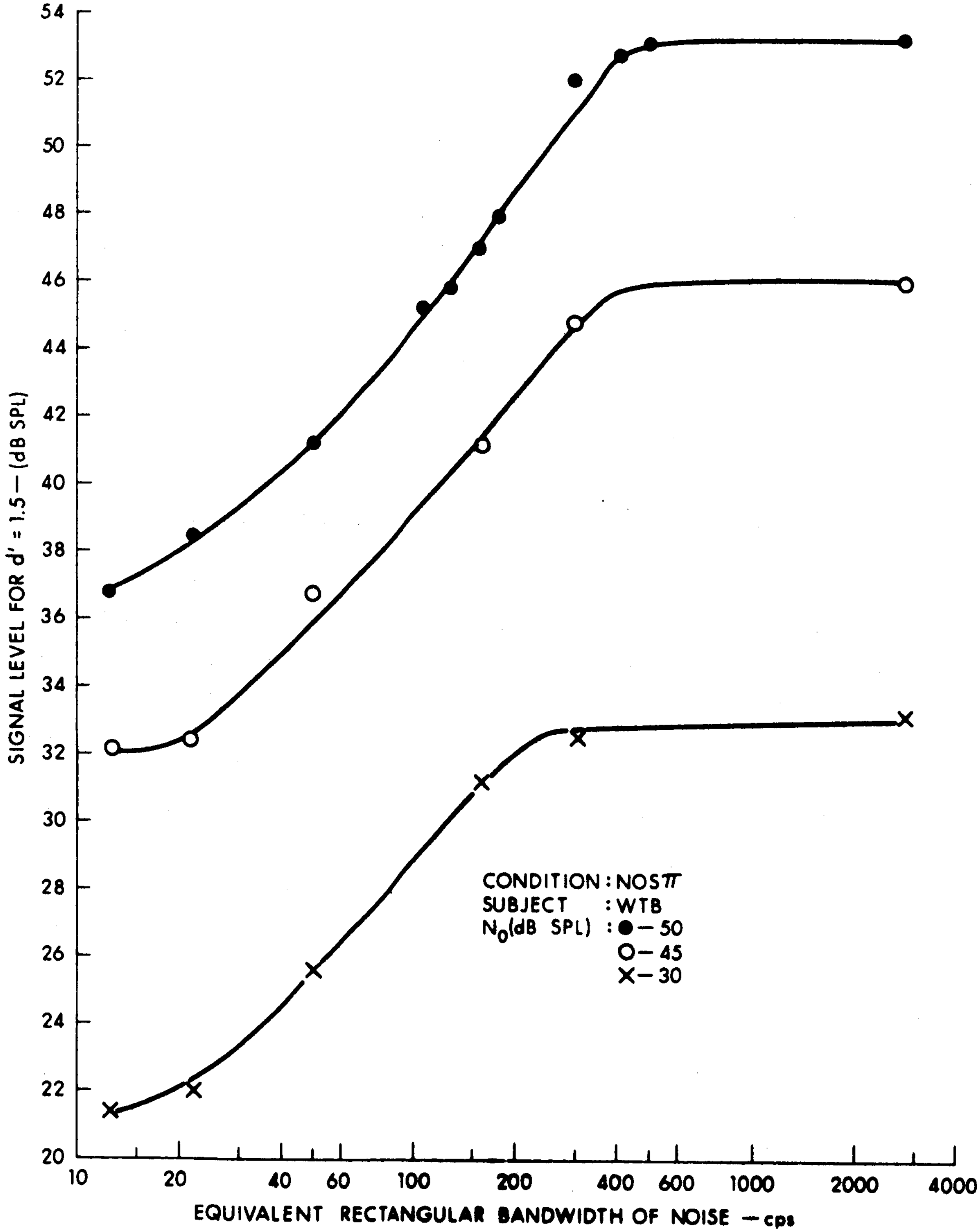
WTB - KLK
7 - 15 - 65

effect of band narrowing is not very significant until a bandwidth of about 50 Hz is reached, whereas AS-65-818 shows very substantial improvement beginning at bandwidths as wide as 200 Hz. The results strongly suggest that a much wider range of frequencies is involved in the detection of a 500 Hz tone under the NO Sπ condition than is involved in monaural or NO SO detection; this is probably not suprising, since we are presumably concerned with a population of auditory nerve cells in binaural phenomena different from these for monaural detection. Neural "funneling", as Békésy calls it, probably occurs in narrowing the bandwidth for monaural detection, whereas probably only the filtering provided by the mechanical action of the basilar membrane determines the bandwidth for binaural detection.

Binaural Electrical Models and Detection

Several electrical models of the binaural detection mechanism have been tested in psychophysical experiments, in an attempt to replicate human performance. Two such models have been run as subjects along with three human observers in a 2AFC experiment. The first model converts the interaural time difference produced when a signal is added antiphasically to an in-phase noise into a voltage which is averaged and sampled at the end of the observation interval. To avoid perfect performance when the noise is in phase at the two ears and the signal reversed in phase at one ear, a small amount of uncorrelated noise is introduced into one channel of the model. This simulates the "noisiness" of the subject's transduction of waveform into nerve impulses. The model yields psychometric functions which fit human functions either at high signal levels or at low, depending upon the noise correlation used. It has not been possible with this device to fit human performance over the whole range of the psychometric function. This fact may be the result of a major inadequacy of the model. It takes into account the time differences based on axis crossings, but it fails to make



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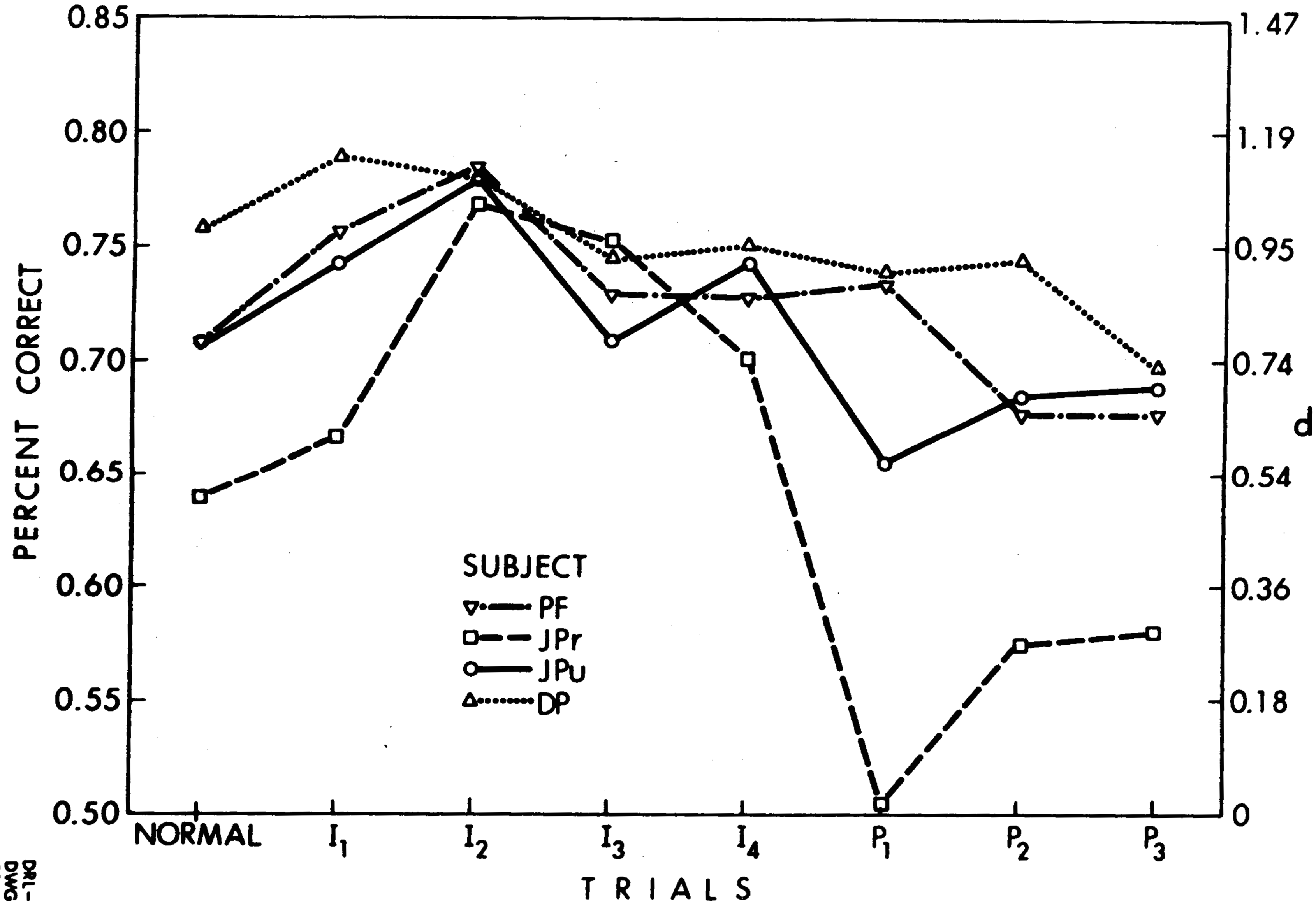
DWG AS-65-818
WTB - KLK
7 - 14 - 65

EFFECT OF BANDWIDTH ON ANTIPHASIC DETECTION use of differences in level which result from adding the signal to the noise. A second model, based on Durlach's Equalization-Cancellation model, has so far failed to perform as well as the one just described. A third model employing the cross correlation between the two earphone channels is under consideration and will be similarly employed if some of its present weaknesses can be eliminated.

Monaural Phenomena

Effect of "Vigilance" in an Auditory Detection Experiment

Many attempts to improve detection by a manipulation of the values and costs matrix have failed to produce an appreciable improvement in detection over a block of trials. The present experiment was undertaken with the idea that enhanced vigilance is a condition which can be maintained for only a short stretch of time. Accordingly certain trials were selected as the "important" trials and their presence was signaled to the subject by means of a light. In the first experiment, the subject was told that these were the important trials and that they must be particularly careful to respond correctly (in a 2AFC setting). This preliminary experiment failed to reveal any improvement on the "important" trials. The next experiments involved various schedules of punishment for incorrect responses on the indicated trials. The punishment was a mild shock (1.6 mA) applied to the ankle, and the experiments differed in the number of successive trials that were included in the critical block. AS-10088 shows the results of one experiment where the number of "important" trials was four. The shock for an incorrect response could occur in any of the four trials. The results show a substantial improvement by the second trial, but a falling off after that. The post-shock trials showed a considerable decrement for two of the subjects with a gradual return to a normal level of performance. The



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EFFECT OF PUNISHMENT ON DETECTION PERFORMANCE first points on the graph are the average for the preceding 16 days of training without the interpolated trials. The findings show that improved detection can be achieved for a very short time but is not maintained. The average for the whole block of trials was the same with and without the shock.

Width and Shape of the "Critical Band" Involved in Masking

There is considerable disparity in the estimates of the width of the "critical band" to be found in the literature. The present study was undertaken to obtain a better idea of both the width and the shape of the band of frequencies involved in masking a 500 Hz signal. It employed a set of high-pass and a set of low-pass filters in order to approach the signal frequency from one side at a time. The results, which are being prepared for publication, show that the shape of the ear's filter is distinctly unsymmetrical having much higher skirts on the low-frequency side than on the high, and that the equivalent rectangular width is of the order of 50 to 80 Hz. One important finding appears to be that subjects differ in their bandwidths. One subject who performed more poorly than the others began to improve at considerably wider bandwidths than the others. That is, he required less narrowing of the masking noise to show improvement than the others did. Apparently in experiments where the task is the detection of a tonal signal, the Fletcher-type estimates of bandwidth are appropriate.

Models: Electrical and Mathematical

The mathematical theory of signal detectability (TSD) is based, in the usual derivations, on sampling theory--on taking a series of 2WT samples of noise (N) or noise plus signal (SN), where T is the temporal duration of the sample. There is some confusion about the meaning of W. Some writers treat it as if it were the bandwidth of the masking components of the noise (the critical bandwidth): others treat W as if it were the bandwidth measured from zero, i.e., as if it were the highest frequency present in the noise sample. In any case, N and SN are sampled in the same way and for the same duration. These assumptions immediately lead us into trouble when we attempt to apply the theory to human observers or to electrical models. The assumption that N and SN are sampled similarly means that they are sampled after being filtered, that is, that the gate follows the filter. In hearing, the filtering is presumably being done by the ear and the gating in advance of the earphone. Thus, the transient responses of the filter become involved. The mathematical theory neglects this aspect of hearing. Also, when we consider the very common experimental condition where the noise is continuous and only the signal is gated for a time, T, we are forced by the mathematical theory to assume that somehow the subject is able to gate the noise in the same way that the experimenter gates the signal--a not very realistic assumption. The question of when and how long to sample becomes one of major concern when dealing with a physical model of the auditory system.

The Role of Signal Duration

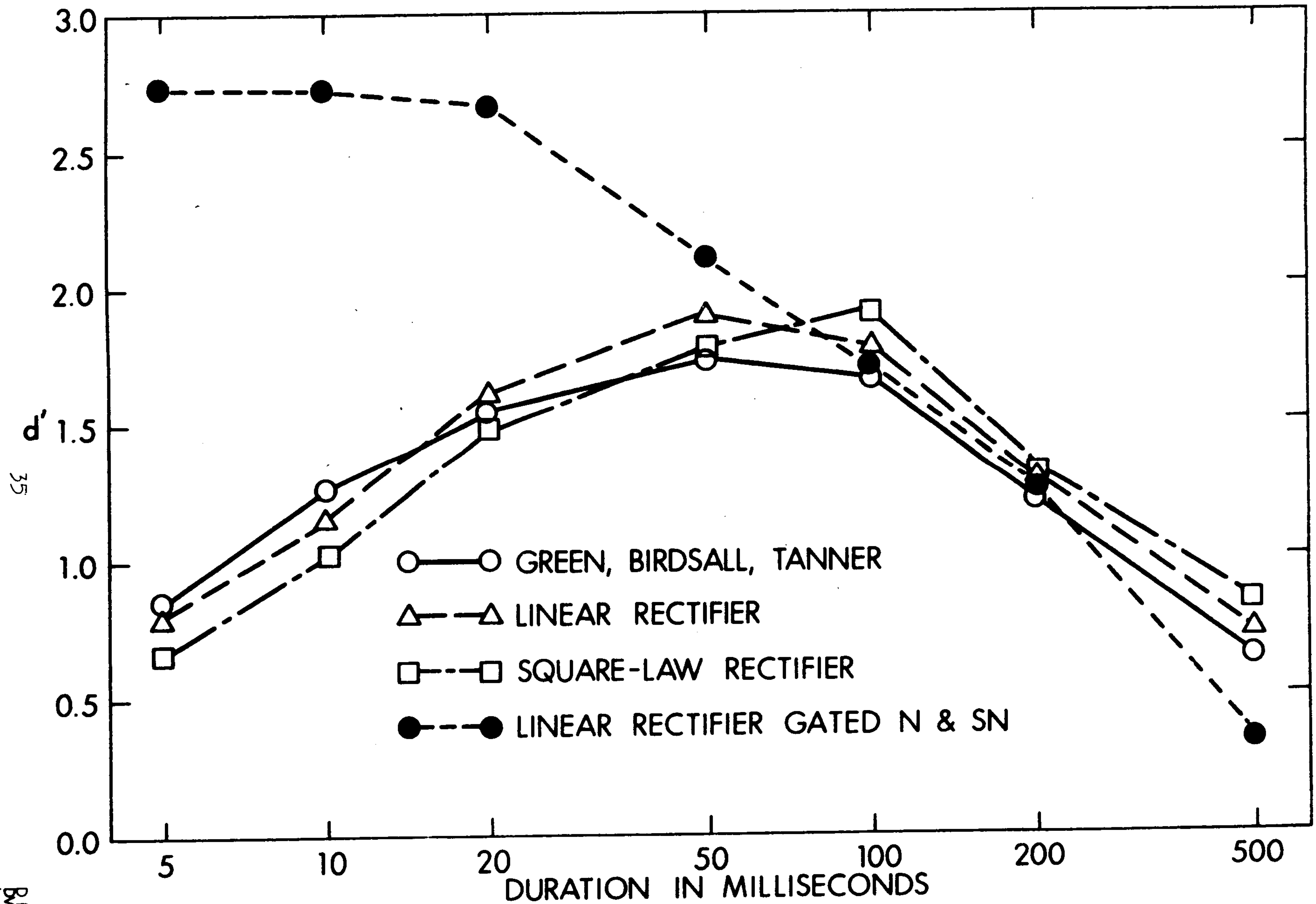
The classic study of the role of duration in the detection of a gated signal in a continuous noise background was made by Green, Birdsall, and Tanner (1957). They employed a constant-energy signal of various durations and used a four-interval forced choice procedure for determining the observers' d's. Their basic finding was that observers did best over a range of durations from about 20 msec to about 200 msec, and fell off rather sharply for durations much longer or shorter than these.

We attempted to replicate the results on signal duration by means of an electrical model which consisted of a narrow filter, a half-wave rectifier, and a post detection (envelope) filter. When the post detection filter had the short time-constant needed to obtain a close-fitting envelope, the data failed to resemble those of the experiment by Green et al. Instead of being reasonably flat across a range of durations, the data showed a decided peak at a duration that was the reciprocal of the filter bandwidth. It was only when we increased the time-constant of the post-detection filter to 50 or 100 msec that we succeeded in replicating the psychophysical data. This time-constant is of the same magnitude as that arrived at by Zwislocki from a very different set of experiments.

Drawing No. AS-66-368 shows the results of the final series of experiments. The circles show the averages for the subjects of the experiment by Green, Birdsall, and Tanner; the triangles, the data obtained with the model using a half-wave rectifier; and the squares show the effect of employing a square-law (energy) detector instead of the half-wave. When the tenets of TSD are more nearly observed, by gating both the masking noise and the signal in the same way, the solid circles were obtained. This suggests that if subjects are presented with gated noise and signal they should perform better, for a constant energy signal, when both the noise and signal are gated than when the noise is continuous and only the signal is gated.

Gated Noise and Signal

Following the lead suggested by the previous drawing we undertook an experiment in which subjects were presented signals of various duration but of constant energy both with continuous noise and with noise gated for the same duration as the signal. AS-66-1036 shows the averages for three subjects. It will be seen that the subjects did perform better with gated noise than with continuous. They did not, however, show, as the model did, continued improvement for gated noise and signal at the short durations.



EFFECT OF SIGNAL DURATION ON DETECTION

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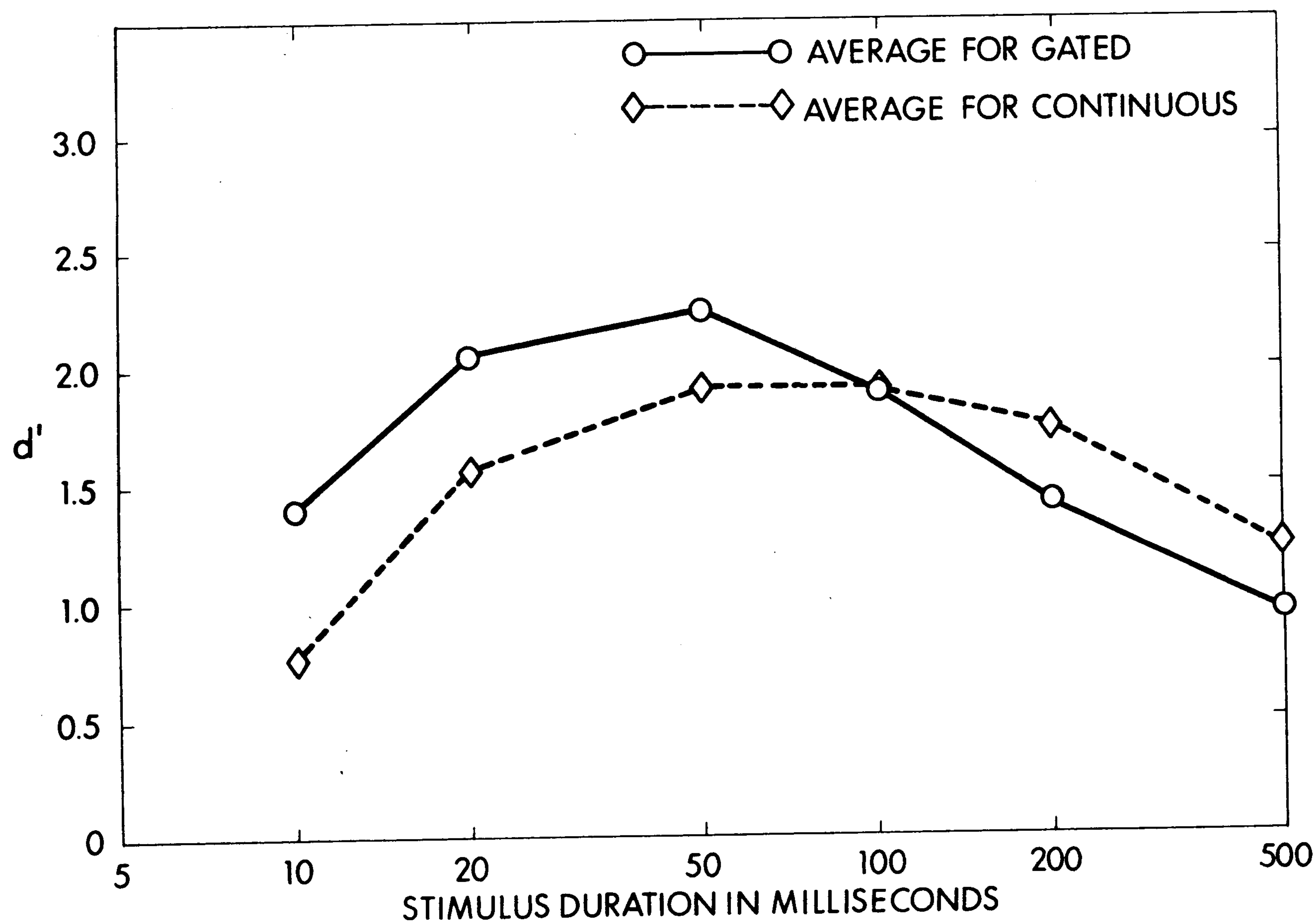

DETECTION FOR CONTINUOUS AND GATED NOISE

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Dr. John Whitmore (a post-doctoral student here) suggested that detection of a signal in a brief gated noise is a very difficult judgment, and that possibly our findings would be different with highly trained subjects. The experiment was therefore repeated using trained observers, with the result that the predicted improvement in performance as the signal was shortened was actually observed. The subjects did better at 5 msec than at 10 and better at 10 than at 20 or 50. The results are being prepared for publication.

Electrical Model as a Predictor of Observers' Responses

Since the electrical model appeared to simulate human performance in several important respects, it was employed as a subject along with human observers in several psychophysical experiments. In the first experiment (by Thomas L. Nichols) it was run as a subject with a human observer in a yes-no experiment (four subjects were tested in this way). It proved to predict the subjects' responses better than whether the signal was present or not. It also proved to be a better predictor than another electrical measure of the stimulus. This was a peak device that recorded the largest envelope peak that occurred during the 250 msec observation interval. Both noise and signal were gated for 250 msec. The two electrical measures showed a correlation of 0.5 to 0.6 for the 250 msec duration. Shorter durations increased the correlation to near unity for very short durations. The 250 duration was chosen to permit the two electrical measures to be reasonably independent with the possibility that they would respond to different aspects of the stimulus and would predict the subjects' responses better than either measure alone. Actually, the peak detector added only about one percent to the predictions of the other electrical model.

A second experiment with the model was carried out--this time employing it with three human observers in a 2AFC experiment using seven levels of signal, and with some trial on which noise alone was presented in both intervals. Table II shows the results.

Table II

E/N_0	$P(C)_m$	$P(C)_{\bar{o}}$	$P(A)_{\bar{o},m}$	$P(A)_{\bar{o},\bar{o}}$	$P(C)_{\bar{3o}}$	$P(A)_{m,\bar{3o}}$
12.8	98.8	92.6	92.4	88.9	99.4	99.1
7.6	91.3	80.4	80.8	76.6	94.1	94.4
5.7	87.3	76.2	77.6	75.2	91.1	93.2
4.8	85.4	72.8	73.6	70.3	87.4	89.8
4.0	79.3	67.2	71.8	70.1	78.7	86.4
3.1	77.0	65.9	72.0	66.5	78.6	88.3
2.5	71.3	60.1	66.1	60.7	68.9	81.7
0.0	50.0	50.0	65.0	63.0	50.0	81.9

The first column is the signal employed, ranging from an E/N_0 of 12.8 to zero--noise alone presented in both intervals. The second column is the percentage correct for the model, and the third is the average percentage correct for the three subjects. It will be seen that the model yields superior detection throughout the range of stimuli. Recent work has shown that we could have obtained a more nearly human fallibility from the model by employing a shorter time constant in the post-detection filter.

The fourth column is the percentage of agreement between the model and the average of the three observers. It will be seen that the model's prediction of the subjects' responses is better than their percent correct. That is to say: the model is predicting their response better than the presence of the signal does. When no signal occurs in either interval, the model predicts their responses 65% of the time.

The fifth column is the average percentage of agreement between one observer and the other two. Comparing this column with column five shows that the model predicts the responses of the human subjects better than they predict each other.

The sixth column is the percentage of correct responses made by the subjects to the stimuli on which all three agreed, whether right or wrong. The column shows that the percentage correct for the stimuli on which the three observers agree is considerably higher than their percentage correct for all of the stimuli. This is of course to be expected--the multiple observer is better than the single observer. The last column shows the agreement of the model with the subjects on those stimuli where the subjects all agree. Again the percentages are higher. Even when no signal is present, the model agrees with the three subjects on more than 80% of the trials.

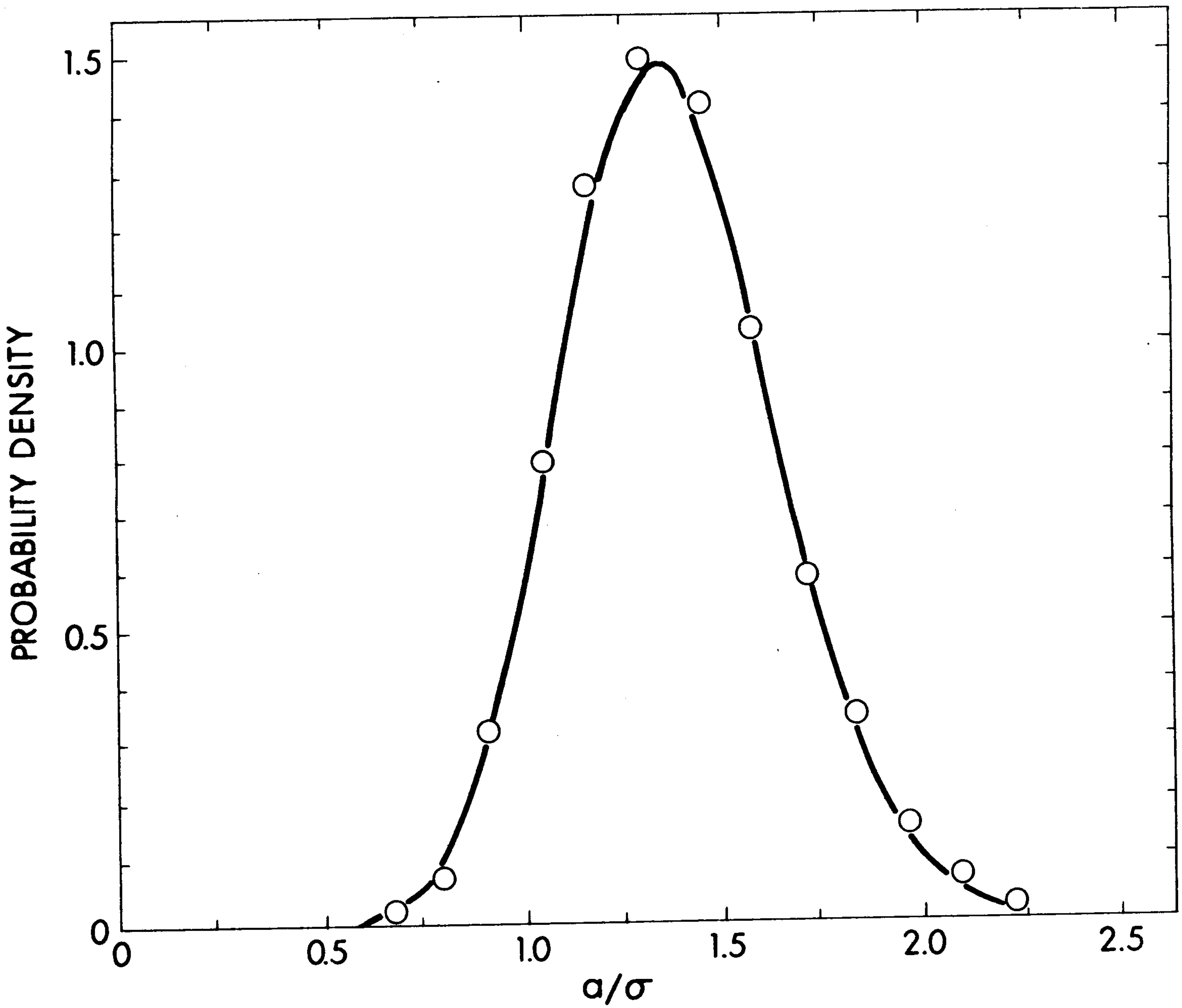
We may conclude that the model is apparently responding to the aspect of the stimulus most important in human signal detection, a considerably smoothed representation of the stimulus envelope.

A Mathematical Model of Monaural Detection

In a recent, brilliant paper, McGill (1967) has shown that the results of an early experiment by Marill (1964) can be explained in terms of an energy-detector model. Marill had employed an envelope detector in his derivations and had arrived at a formula for predicting the percentage of correct responses in a two-alternative, forced-choice experiment. McGill arrives at the same formula by way of an energy detector. He assumes that a narrow band of noise, or noise plus signal, is gated for a time T, the resulting voltage is squared and then integrated. The integrator is discharged between observations. From the statistics of this device he derives Marill's equation. He then goes on to show that the bandwidth assumptions made by Marill in fitting his theoretical function to human observers are inappropriate, and that a better adjustment can be made by assuming a different number of degrees of freedom in the probability functions. He shows that the Rayleigh-Rice statistics employed by Marill can be replaced, and more generality achieved, by employing the noncentral chi-square distribution.

The electrical model we have been discussing is capable, not only of voting in a 2AFC experiment, but by recording samples of its output, of generating the distribution functions of its underlying statistics. We find that if we sample the noise distributions measured at the output of the post-detection filter, we obtain a probability density function which resembles, but differs from, the Rayleigh distribution. It is less skewed, but still has considerable skewness. It does not resemble any chi-square distribution. The resemblance to the Rayleigh distribution suggests that the appropriate function would be a Rayleigh-like distribution with more degrees of freedom, and this proves to be a special case of the chi density function. AS-67-1551 shows a chi distribution with 14 deg of freedom. The points represent 10,000 samples of the output of the post-detection filter.

Since the chi distribution fits the data for noise alone, the next question is whether the noncentral chi distribution with the same number of degrees of freedom will fit the data for noise plus signal. AS-67-1552 shows the resulting "psychometric" function. The abscissa is signal-to-noise ratio and the ordinate is the difference of means divided by the standard deviation of the



CHI DISTRIBUTION $\nu = 7$ AND DATA FROM ELECTRICAL MODEL

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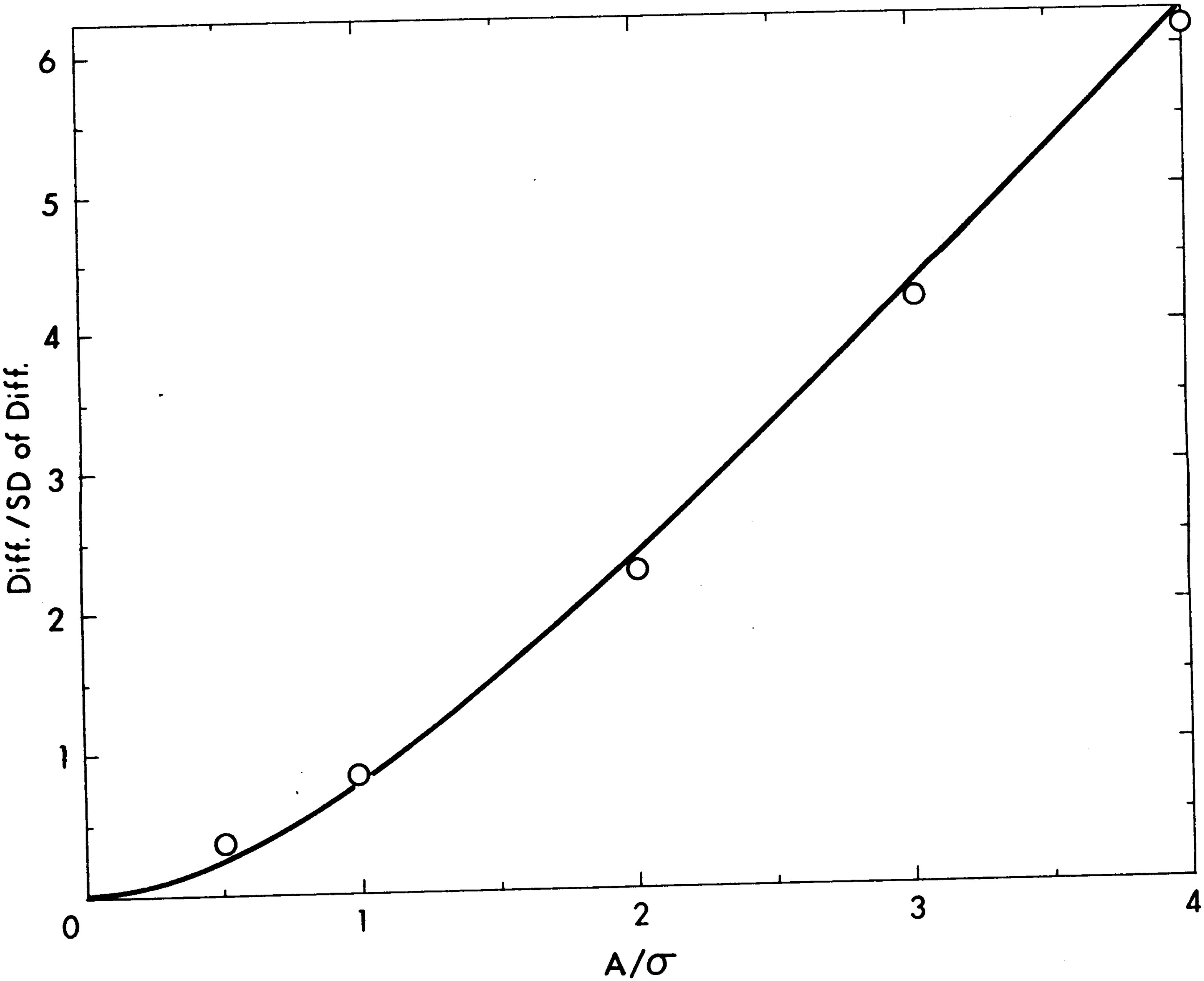

NONCENTRAL <u>CHI</u> DISTRIBUTION AND DATA FROM ELECTRICAL MODEL

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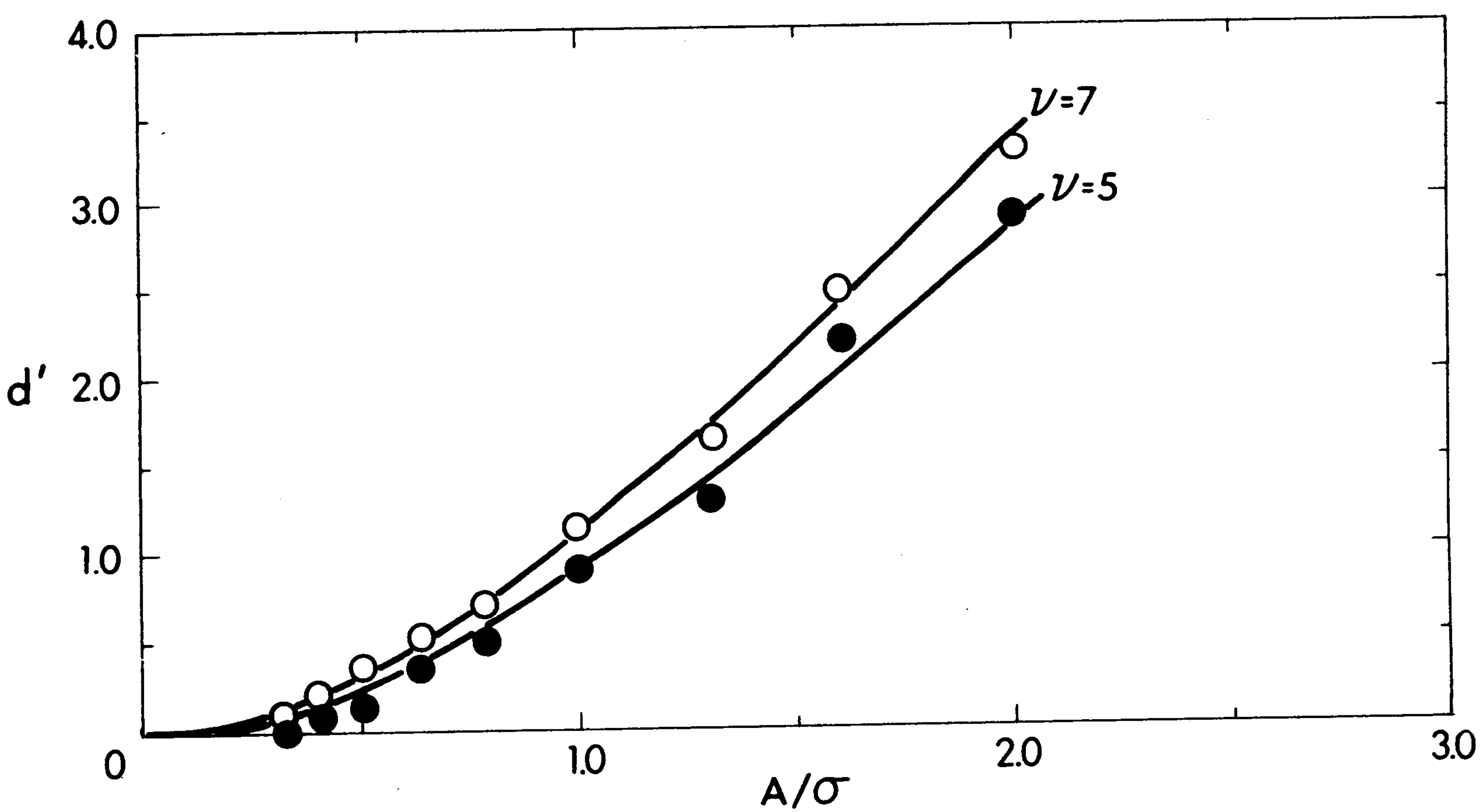
difference. The fit appears to justify the assumption about the appropriateness of the distribution functions.

Noncentral Chi Distribution and Psychometric Data

Drawing No. AS-67-1553 shows the same chi distribution and another with 10 deg of freedom along with data for Marill's two subjects. It will be seen that one of the subjects fits the curve for $v = 7$ (14 deg of freedom) very well. The other subject apparently requires fewer deg of freedom and even then yields a rather ragged fit. Apparently the parameters chosen for the electrical model (50 Hz bandwidth and a time-constant for the post detection filter of 50 msec) correspond reasonably well with the parameters employed by the first subject. The data for the second subject requires the assumption that he employ either a wider filter (Marill's conclusion) or that his integration time is shorter. At the present state of our knowledge of individual differences it is not possible to decide which (or both). The raggedness of the second subject's fit also suggests that nonstimulus factors are influencing his behavior, attention lapses, indecision about which button to press, etc.

The rather surprising agreement between the data for the model and for one of Marill's subjects suggests that this subject, like the model, is governed in his responses almost wholly by the statistics of the stimulus. The parameters chosen for the distribution employed are well within the range of values estimated for detection experiments--a "critical" bandwidth of 50 Hz and a time constant of 50 msec. The latter is the figure recently reported by Zwislocki for the auditory system.

The studies with the model and the mathematical developments have been prepared for publication in the Journal of the Acoustical Society of America.



NONCENTRAL <u>CHI</u> DISTRIBUTION AND PSYCHOMETRIC DATA

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