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ATTENTION VALUE OF AUDIO AND VISUAL WARNING SIGNALS

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FOREWORD

This investigation was initially conducted under Air Force Contract Number 33(616)-135, Project 7186, Task 71550 and was later transferred to Project 7184, Task 71580. The Engineering Psychology Branch, Aero Medical Laboratory, Wright Air Development Center acted as the monitoring organization with Dr. James M. Vanderplas, Lt. Colonel Anthony Debons and Dr. Dwight E. Erlick successively acting as Task Scientists. Special acknowledgment is given Dr. St. Clair Switzer of Miami University, Oxford, Ohio, for his efforts in the editing and revision of this report.

ABSTRACT

A comparison was made of the attention-demanding values of auditory stimuli differing in frequency, and of visual stimuli differing in wave length under different conditions of background noise. Following a survey of the literature, a method was developed which was intended to provide a laboratory analogue of real tasks and which lent itself to measurements of stimulus-effectiveness in attracting the attention of the subject. Quantitative measures could now be obtained both by threshold techniques and reaction time techniques.

With respect to the practical problem of designing systems of warning signals, the results indicate that engineers and engineering psychologists are justified in utilizing the substantial body of knowledge already established concerning sensory thresholds, and their dependence on frequency, as a guide in the selection of stimuli to be used as warning signals. No statistically significant change in the form of sensory threshold curves results from distraction of the individual by a task.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published only for the exchange of information and stimulation of ideas.

FOR THE COMMANDER:

Walter F. Grether

WALTER F. GRETHER
Director of Operations
Aero Medical Laboratory

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I. INTRODUCTION

The present report provides a summary of a series of investigations carried out on the problem of the "attention-demand" value of certain sensory stimuli. This research was undertaken to obtain facts that might be of value to the Air Force in attempts to design more effective systems of warning signals. In the design of such systems, it would presumably be of value to know whether there are certain stimulus values within a sense modality which are maximally effective in attracting the attention of a subject when he is engaged in a task.

There are two principal questions with which the present research is concerned: (1) What additional methods beyond those already reported in the literature can be proposed for measuring the attention-demand value of sensory stimuli? (2) Is there any significant effect of frequency or wave-length of the stimulus upon its attention-demand value, in the modalities of audition and vision?

A. On Attention in General

A bibliography covering the entire field of attention was compiled and the items in this bibliography were classified according to the topics after the system of Kreezer, Hill and Manning, 1954. A supplement to this 1954 bibliography has been compiled and is included as Appendix III.

B. On Methods of Measuring Attention-Demand Value

An examination of methods previously described for measuring the attention-demand value of stimuli indicates that they are all based on attempts to measure certain properties of the response to a given stimulus. In the method developed in the present investigation, on the contrary, a measurement is proposed for the properties of the stimulus necessary to bring about a specified constant, or standard response. In this method the response adopted as standard has been the "just-noticeable-response". The method may therefore be characterized as an absolute-threshold-method, based on such modifications of standard psychophysical methods for measuring absolute sensory thresholds as were considered necessary to permit determination of a quantitative index of

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attention-demand value. A description of this method has already been published (2).

The earlier methods for measuring attention-demand value based on properties of the response can be grouped into three classes: (a) methods based on specification of the clearness or vividness of the sensory experiences elicited by the stimulus, (b) methods based on the reaction-time of the response to a specified stimulus, and (c) methods based on the fixation-time of the eyes in investigations of attention-demand value of visual stimuli.[1]

II. METHOD

A. Background Considerations Suggesting Threshold Measurement of Stimulus-Effectiveness

The method utilized in the experimental studies reported below is based on an extension of the concept of the absolute threshold to the measurement of the attention-demand value of stimuli. Methods described in the past for measurement of the attention value of stimuli are all based on a measurement of some property of the response to a given stimulus as pointed out above. The present method shifts the focus of attention to the stimulus, and attempts to determine the effectiveness of a stimulus in attracting the attention of a subject, by directly measuring the magnitude of the stimulus required to just bring the stimulus to the point of perception, when he is already engaged in a standard task.

The problem of determining the attention-demand value of a stimulus belongs to the general class of problems in which one wishes to determine the effectiveness of a stimulus under certain specified conditions. We find this type of problem arising both in physiology and in sensory psychology.

In neural physiology, for example, the problem arises in two different settings, one, in attempts to compare the excitability of different nerves, and two, in attempts to compare the effectiveness of electrical stimuli of different temporal patterns.

In the measurement of nerve-excitability, the procedure of

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[1] References to papers on these three types of method are given in in footnotes 3, 4, and 5 respectively of the paper on the threshold method (2).

measuring the stimulus rather than the response seems natural in view of the phenomenon of the all-or-none character of the response in single cells. If the response cannot be made to vary in magnitude, one is forced to the artifice of measuring the stimulus. Information on the excitability of the tissue is then provided by regarding the excitability as the reciprocal of the threshold. Even though the investigator's interest is in the properties of the response system, the experimental determination (or operational procedure) is that of determining a threshold, e.g., the lowest voltage of a rectangular pulse of a given duration that brings about a response. In the case of a single axon the response would always be approximately constant in magnitude. In the case of a compound nerve, made up of many axons, it may be necessary to standardize on the just detectable response. The experimental problem in the case of nerve is somewhat complicated by the fact that all durations of pulse are not equally effective. However, by obtaining a threshold for each of a series of durations of stimulus-pulse, the experimenter obtains a strength-duration curve, which represents the variation of threshold value with changes in duration of rectangular pulse. This curve can now be regarded as representing the excitable properties of a given tissue. The higher the threshold at a given point on the curve, the less excitable is the tissue.

A second type of problem in neural physiology is that of comparing the effectiveness of different kinds of agents capable of stimulating the nerve. If we restrict our consideration to electrical stimuli, we find variation possible in the temporal form of the applied voltages. Thus the question has been raised of the relative effectiveness of alternating voltage as compared to rectangular D.C. pulses, and of the relative effectiveness of different durations of rectangular pulses. This type of question is more directly analogous to the question raised in the present investigation of attention-demand value of stimuli. In the physiological case, the question of comparative effectiveness of stimuli is answered by obtaining thresholds for each of the different types of stimulus.

If we turn now to sensory psychology, we find similar questions raised and a resort to similar methodology. In references to visibility and audibility curves, and to audiograms, we find a concern with problems analogous to that of determining the excitability of nerves, namely that of determining the responsiveness of specific sensory systems. Again, measurement is made by varying the intensity of the stimulus, and determining the weakest stimulus just capable of bringing about a response - in short, by determining absolute thresholds. The conventional procedures for obtaining thresholds, embodied in the methods of limits and of constant stimuli, can be considered as representing merely different ways of dealing with statistical variability. The possibly disturbing effects of variation in the subject's set or state of readiness for a given stimulus is controlled by making him familiar with the kind of stimulus to be presented, and providing him with a warning signal so he can set himself to expect the stimulus. Due to this standardization of the subject's set, differences in threshold are now attributed to differences in excitability of the sense-organs or receptors even though the whole organism, or at least sensory-motor mechanisms and cerebral cortex, must also participate in order for the subject to be able to make his report.

Inquiries concerning the relative effectiveness of different kinds of stimuli, and different temporal patterns of stimuli in arousing response, have not been as prominent in sensory spheres as in the neuro-physiological. The infrequency of this type of inquiry rests primarily on the fact that sensory thresholds are usually obtained with durations of stimulus-pulse so long that further increases in duration will no longer change the intensity-threshold. Psychologists, therefore, are less likely to recognize the need of a strength-duration curve to represent differences in effectiveness of stimulus-pulses of different duration. Some investigators, (e.g., Fessard) influenced by the work on chronaxie of Lapicque and his school, have realized the relevance of the time-factor in the sensory field as well as the physiological, and have obtained analogous curves, showing how the intensity thresholds for sensory response may vary with duration of the stimulus-pulse. So again we find a procedure for comparing the effectiveness of different kinds of stimuli through the use of threshold determinations.

When we consider now the question of obtaining a measure of stimulus effectiveness that may be designated as a measure of attention-demand value, the basic approach described above seems relevant. In view of the prominent role which threshold procedures have played in determining stimulus-effectiveness at the neural and sensory levels, it might even be argued, on the grounds of logical continuity, that a threshold method can be considered a more basic approach to the measurement of attention-demand value than can measurements based on quantitative variations in the response.

B. A Threshold Method for Measuring Attention-Demand Value of Stimuli

The following summary of the threshold method used in the experimental part of this study is taken from the recently published paper on the method (2). Further details and the rationale behind the procedures adopted may be found in other sections of that paper.

A sequence of pulses of increasing intensity is presented, without any warning signal, while S is engaged in a task, designated hereafter as the steady-state task. He responds, on the basis of previous instructions, to the first pulse he perceives, Pulse A, by pressing a key. The intensity of this pulse, in db., is designated as the task-threshold.

Following an interval of about 6 sec., a second series of pulses is presented. The S, if he is following instructions, should now be "set" for the stimulus. In the case of tonal stimuli, he is listening for them. Again, he responds by pressing a key as soon as he perceives one of the pulses, Pulse B. The intensity of this pulse is designated as the set-threshold.

From the point of view of S, the only stimuli presented are Pulses A and B. Pulse A, perceived while he is engaged in the steady-state task, is regarded by him as a warning signal (again on the basis of previous instructions), a signal to stop giving attention to the task, and to listen for a weak stimulus of the same kind as he has just heard.

From the point of view of E, Pulse A provides a measure of task-threshold and Pulse B of set-threshold, the latter representing the absolute sensory threshold for a particular stimulus. If the stimuli are each measured in logarithmic units, such as db., the difference between the two intensities furnishes a basis for comparing the attention-demand value of different stimuli. In general, the task-threshold will be greater than the set-threshold; but by subtracting the task-threshold from the set-threshold we obtain an index of attention-demand value which increases in level as attention-demand value increases.

Although the present method was fashioned with the goal in mind of obtaining thresholds, reaction-times to the terminal stimuli A and B also may be obtained. With reaction time-data as well as threshold-data for the same set of stimuli, it becomes possible in a given investigation to compare reaction time measures of attention-demand value, frequently used in the past, with the new threshold-measure.

The description just given represents the minimum presentation of stimuli required in order to obtain an index of attention-demand value. The task-threshold alone, corresponding to but a single ascending series, or ramp, is not sufficient, because of the known differences in sensitivity of visual and auditory sense organs at different stimulus-frequencies. The second ascending series, with an appropriate modification in the set of the subject, is introduced to provide for a determination of absolute sensory threshold, or "set-threshold." The set-threshold, thus determined at each frequency, can be used to correct the task-threshold for differences due to variations in receptor sensitivity with frequency. The attention-demand index is the measure which embodies this correction.

Although an attention-demand index for a given kind of stimulus might be determined from but a single presentation of a pair of ramps, as described above, it is desirable, as in any other experimental determination, to provide for a sufficient number of repetitions of the pair of ramps, or double ramp, to permit statistical estimates to be made of the reliability of the attention-demand index attributed to any specific stimulus. In an experimental period of about 45 minutes, during which the subject was engaged in the standard steady state task, it was found possible to provide for five repetitions of a double ramp for each of five stimulus frequencies used, with an average interval between each presentation of a double ramp of 1 1/2 minutes. The actual time interval used in successive trials is varied, and the order of such intervals and the order of the stimulus-frequencies (pitch) presented successively are randomized to minimize any tendency on the part of the subject to get set for the appearance of the stimulus.

By way of summary, it may be stated that the method utilized here provides (1) a task-threshold for a given stimulus, (2) a set-threshold for that same stimulus, and (3) an attention-demand index based on the difference, in decibels, between the task-threshold and the set-threshold.

Efforts to determine a valid task-threshold, defined as the threshold obtained for a given stimulus when the subject is engaged in a task, involved imposing certain requirements with respect to the characteristics of the task and the set or attitude of the subject, as well as modifications in the psychophysical method of limits which was used as a starting point for the method used in obtaining threshold-values. These special features of the method are described elsewhere (2).

In the presentation of the statistical data relating to the attention-demand value of stimuli, two indicators will usually be considered, one based on the task minus set threshold difference, and one based on the task minus set reaction time difference. In the paper on method, (2), an attention-demand index was defined, which is arithmetically identical in magnitude to the task-set threshold difference, but shows merely a reversal of sign. Further, since the task-set threshold difference will typically be positive in sign, the attention-demand index will be negative in sign. In our investigation of the role of special factors such as frequency, in determining attention demand value, it is not necessary to make this conversion of sign.

Hence, the various analyses will be based on task minus set threshold differences taken as the individual items rather than on the attention-demand index. The latter is expected to be more convenient when we wish to specify quantitatively the attention-demand value of specific stimuli.

The essential problems involved in the experimental studies which follow are: (1) determining whether the task-threshold is significantly greater than the set-threshold, and (2) determining whether or not there is any significant effect of stimulus-frequency on the attention-demand index. The apparatus used for presentation and measurement of the performance of the subjects on the steady-state task, and for presentation of test-stimuli and recording of threshold values are described in Appendixes I and II.

III. EXPERIMENTAL STUDIES ON THE ATTENTION-DEMAND VALUE OF AUDITORY STIMULI AS A FUNCTION OF STIMULUS-FREQUENCY[2]

A. With a One-Dimensional Compensatory Tracking Task, and No Background Noise

The data and results of this study will be published separately. The results were as follows: (1) A highly significant effect of the task in raising the absolute threshold of all frequencies of auditory stimuli utilized. (2) No statistically significant effect of stimulus-frequency on attention-demand value.

B. With a Two-Dimensional Compensatory Tracking Task and No Background Noise

In a second experimental study with a new group of subjects the following changes were made in the conditions: (1) A two-dimensional compensatory tracking task was substituted for the one-dimensional task of the previous experiment. (2) Reaction-time measurements were made simultaneously with the threshold determinations for all stimuli. (3) There were three replications of the experimental series for all subjects.

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[2] All of the experimental studies involving auditory stimuli were carried out with Mr. Henry Ellis as research assistant.

The substitution of a two-dimensional compensatory tracking task, as a steady state task, was intended to provide the subject with a more difficult task, one requiring a higher level of continuous effort and attention to the task. It was felt that any such increase in the attention given by the subject to the task should result in larger task minus set threshold differences. Such an increase (if the error variance did not simultaneously increase) would increase the likelihood of detecting significant differences in attention-demand value associated with frequency, if such differences did in fact exist. Larger task-set threshold differences would provide a wider range within which the threshold differences possibly associated with frequency might show up. In terms of analysis of variance concepts, we would expect a larger estimated variance based on differences between frequency-groups, with no increase in error variance. If such a change occurred, the F-ratio, computed to determine the effect of frequency, would also be correspondingly larger, and might now be significant. These considerations indicate the importance, in the present method, of using a steady state task capable of inducing a maximum degree of attention on the part of the subject.

The circuitry required for making reaction-time measurements to the same stimulus-pulses used in obtaining thresholds was not available when the previous experimental series was run. Its availability for the present series makes it possible to use both the threshold measures and reaction-time measures of attention-demand value in investigating the effect of stimulus-frequency.

In the present study, there was a total of three replications of the experimental series for each subject, the successive experimental runs being spaced at intervals of about one a week. These replications were intended to provide additional evidence concerning the reliability of the results, and to determine whether there was any systematic effect produced by repetition of an experimental series.

Results. The results may be conveniently summarized by relating them to a number of specific questions.

(1) Is the Task-Threshold Significantly Greater than the Set-Threshold? What we are trying to determine here is whether the attention given by the subject to the steady state task produces a statistically significant increase in the absolute sensory threshold. This question can be most simply answered through the application of a simple t-test to determine whether the mean task-set threshold difference, which can be obtained for every presentation of a double ramp, is significantly

greater than zero. Table I shows the results of applying this test to the data from each of the three experimental series. It is apparent from a comparison of the t obtained and that required at the .01 level of confidence that the effect of the task in increasing the threshold level is highly significant. This result supports the assumptions made in developing the present method for measuring attention-demand value. In case a significant effect of the task in increasing the threshold had not been found, we should not be justified in proceeding further to use such an increase as an indication of differences in the attention-demand value of different stimuli.

TABLE I

DATA INVOLVED IN THE COMPUTATION OF t TO DETERMINE WHETHER THE TASK HAS A SIGNIFICANT EFFECT IN RAISING THE THRESHOLD

Series	M_D	S.D.	$S.E._M$	df	t obt:	t required 1 % level	Significant?
1	7.91	5.77	0.37	249	21.38	2.601	Yes
2	5.94	4.49	0.28	249	21.21	2.601	Yes
3	4.42	5.15	0.33	249	13.39	2.601	Yes

LEGEND

M_D is the mean of the task-set threshold differences obtained in 250 trials in each series.

S.D. is the standard deviation of the distribution of threshold differences.

$S.E._M$ is the standard error of the mean df is the degrees of freedom involved.

t obt. is the ratio M_D/SE_M.

t required states the value of t required at the .01 level of confidence, as taken from Fisher's t-table (cf. Waugh, 1952, p. 82).

(2) Is There a Statistically Significant Effect of Stimulus-Frequency on Attention-Demand Value?

The relevant data are summarized in Tables II through VII, showing the results of analyses of variance carried out upon the data obtained from experimental series 1, 2, and 3.

Let us first consider Tables II, III, and IV, giving the data with respect to task minus set threshold differences. Inspection of the second row of these tables, representing the effect of variations in the stimulus-frequency, reveals that the F ratio obtained (equal to the variance due to the "between-frequency" groups divided by the "error-variance") is in each of the three series well below that required even at the 5% level of confidence. The frequencies involved

TABLE II

ANALYSIS OF VARIANCE OF THRESHOLD-DIFFERENCE:
AUDITORY STIMULI, ZERO BACKGROUND NOISE

Series #1

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required 5% level	F required 1% level
Within Subclasses (Error)	200	7,077.49	35.387			
Frequency (Fr)	4	49.98	12.495	0.353	5.65	
Subjects (S)	9	1,887.95	209.772	5.928**	1.92	2.50
Interaction (Fr x S)	36	1,185.13	32.920	0.930	1.59	
Total	249	10,200.55				

**Significant beyond 1% level of confidence

TABLE III

ANALYSIS OF VARIANCE OF THRESHOLD DIFFERENCE: AUDITORY STIMULI, ZERO BACKGROUND NOISE

Series #2

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required	
					5% level	1% level
Within Subclasses (Error)	200	3,994.35	19.971			
Frequency (Fr)	4	93.67	23.417	1.172	2.41	
Subjects (S)	9	1,575.51	175.056	8.765**	1.92	2.50
Interaction (Fr x S)	36	435.98	12.110	0.606	1.59	
Total	249	6,099.51				

TABLE IV

ANALYSIS OF VARIANCE OF THRESHOLD DIFFERENCE: AUDITORY STIMULI, ZERO BACKGROUND NOISE

Series #3

Source of Variance	df	Sum of Squares	Mean Squares	F obtained	F required	
					5% level	1% level
Within Subclasses (Error)	200	5,002.76	25.013			
Frequency (Fr)	4	34.72	8.680	0.347	5.65	
Subjects (S)	9	1,082.00	120.022	4.798**	1.92	2.50
Interaction (Fr x S)	36	1,584.73	44.020	1.759*	1.52	1.79
Total	249	7,704.21				

*Significant beyond 5% level of confidence

**Significant behond 1% level of confidence in these comparisons are 250, 500, 1000, 2000, and 3000 cycles per second. There is thus no evidence of a significant effect of frequency on the attention-demand values of stimuli, when the task-set threshold difference is assumed as a basis for determining attention-demand value of stimuli.

Let us now consider Tables V, VI, and VII, giving the data with respect to the task reaction time minus set reaction time difference. Inspection of the second row of these tables, relating to the effect of stimulus-frequency, shows here, too, F-ratios that are below the 5% level of significance, for each of the three series. Thus the reaction time difference, used as an indicator of attention-demand value, also fails to reveal any significant effect of frequency on attention-demand value of the stimulus.

TABLE V

ANALYSIS OF VARIANCE OF REACTION-TIME DIFFERENCE: AUDITORY STIMULI, ZERO BACKGROUND NOISE

Series #1

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required 5% level	F required 1% level
Within Subclasses (Error)	200	37,719,479	188,597			
Frequency (Fr)	4	511,439	127,859	0.678	5.65	
Subjects (S)	9	5,122,616	569,179	3.018**	1.92	2.50
Interaction (Fr x S)	36	8,135,679	225,991	1.198	1.52	
Total	249	51,489,213				

**Significant beyond the 1% level of confidence

TABLE VI

ANALYSIS OF VARIANCE OF REACTION-TIME DIFFERENCE: AUDITORY STIMULI, ZERO BACKGROUND NOISE

Series #2

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required	
					5% level	1% level
Within Subclasses (Error)	200	32,160,180	160,801			
Frequency (Fr)	4	668,389	167,097	1.039	2.41	
Subjects (S)	9	2,595,319	288,369	1.793	1.92	
Interaction (Fr x S)	36	5,562,800	154,522	0.961	1.59	
Total	249	40,986,688				

TABLE VII

ANALYSIS OF VARIANCE OF REACTION-TIME DIFFERENCE: AUDITORY STIMULI, ZERO BACKGROUND NOISE

Series #3

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required	
					5% level	1% level
Within Subclasses (Error)	200	26,801,348	134,007			
Frequency (Fr)	4	486,532	121,633	0.908	2.41	
Subjects (S)	9	2,829,654	314,406	2.346*	1.92	2.50
Interaction (Fr x S)	36	4,822,454	133,957	0.000		
Total	249	34,939,988				

*Significant beyond the 5% level of confidence

(3) Subordinate Effects. It is of interest to consider the effect of two additional factors on the task-set threshold difference and the task-set reaction time difference, namely, (a) differences between individuals, and (b) the repetition of the experimental series by the subjects at weekly intervals.

The effect of individual differences is readily exhibited by the analysis of variance tables. Tables II, III, and IV show that subject-differences have a statistically significant effect upon task-set threshold differences, beyond the 1% level of confidence, in each of the three experimental series. The interaction entries, showing the effect of interaction between subject and frequency variables, show a non-significant effect in Series 1 and 2, but a significant effect in Series 3. There is thus an indication that the individual differences, among subjects, in the task-set threshold difference vary with the frequency of the stimulus, at least in the last experimental series.

Examination of Tables V, VI, and VII, relating to reaction-time differences, shows that subject variability produces a significant effect in Series 1 at the 1% level, no significant effect in Series 2, and a significant effect in Series 3 at the 5% level. This greater deviation from the consistency of the results for reaction-time data is a possible consequence of greater instability in the reaction-time measurements, a point suggested by some of the other findings, and which will be considered in the discussion. The interaction of subject and threshold is found not to be significant in all three series.

The effect of repetition by the subject-group of the experimental series at weekly intervals is shown by an examination of Figures 1 and 2. Figure 1 gives the curves representing the task-set threshold difference as a function of stimulus-frequency for each of the three experimental series. It is apparent that the level of the curve progressively falls with each repetition of the experimental series. This result may possibly be accounted for in terms of a change in the attitude of the subject toward the steady state task. With greater familiarity with the task, it may elicit less effort and thus become less attention-demanding, despite instructions, with a consequent decrease in the effect of the task in increasing the absolute stimulus-threshold.

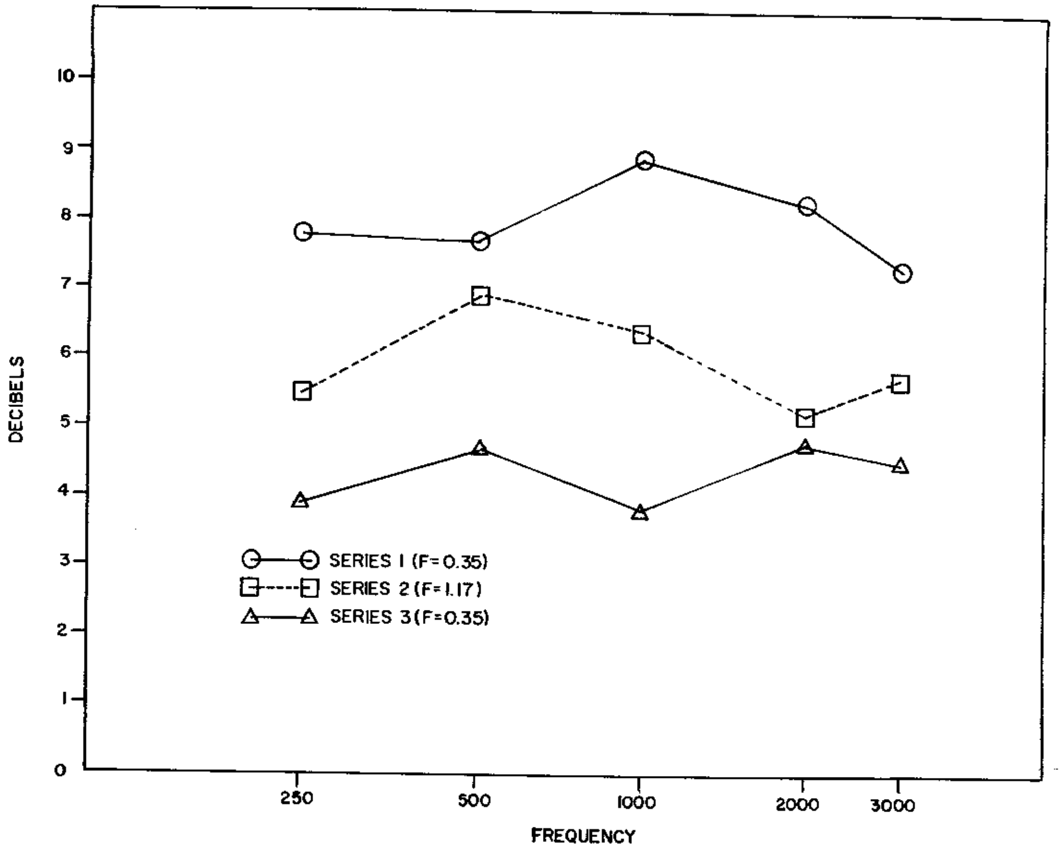

Figure 1. Mean Task Minus Set Threshold Difference as a Function of Frequency of Auditory Stimulus, for Each Experimental Series. (F-Values Given Are Those Determined from Analysis of Variance. None Are Significant).

Figure 2 shows corresponding curves for the reaction-time difference. It is more difficult to state the effect of repetition upon the task-set reaction time difference curves. The curve representing Series 1 lies above the other two curves, indicating a tendency for the magnitude of the reaction-time difference to decrease with repetition of the experimental series, but the change is not marked except at two frequencies, 1000 and 2000 cycles per second. The curves for Series 2 and 3 lie at about the same level. It is striking that both of these curves lie on the negative side of the graph about as much as on the positive side, indicating that the excess of task reaction time over set reaction time is evident only in the first series,

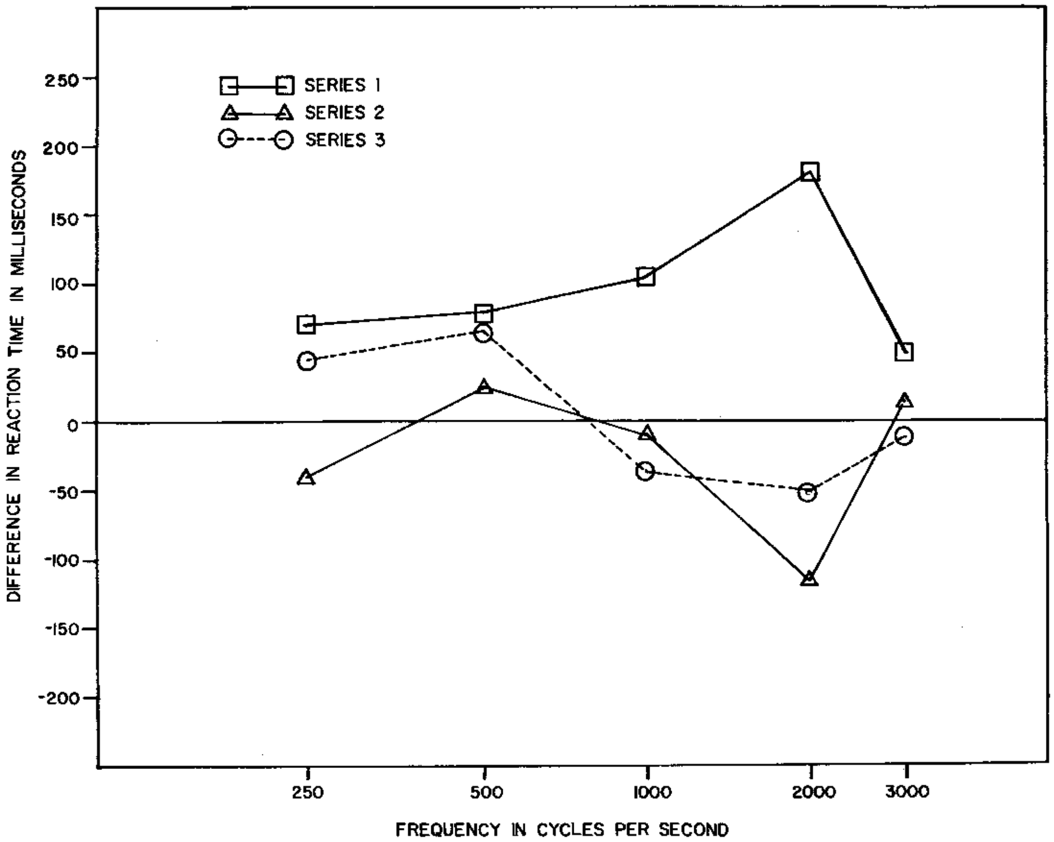

Figure 2. Mean Task Minus Set Reaction-Time Difference as a Function of Frequency of Auditory Stimulus, for Each Experimental Series.

before the subject becomes habituated to the task. Following this period, there is no appreciable evidence of a difference in reaction time between the task and set conditions.

C. With a Two-Dimensional Compensatory Tracking Task, and High Level Background Noise

The essential change involved in the present experimental study was the provision of high intensity background noise in order to more closely simulate conditions expected to be operative in aircraft. In order to provide for this background noise, some changes were required in the procedures used for presenting the test-stimuli to the subjects. The subjects now wore a binaural set of ear phones during the experimental series, the stimulus-tones being presented monaurally through the left ear phone only. Additional amplification of the stimulus test signals was also required so that the range of intensities available would be suitable for determination of thresholds despite the masking due to background noise. To provide the background noise, a loud speaker was located five feet behind the subject. The source of noise was a General Radio white noise generator, amplified by means of a Bogen, Model DE 150 power amplifier. The level of noise at the position of the subject's left ear phone, while he is engaged in tracking, is 80 db, relative to 0.0002 dynes per sq. cm., as measured by means of an Altec-Lansing Model M 14 calibrated condenser-microphone system and a Ballantine Model 300 vacuum tube voltmeter. A new group of ten subjects was used in this experiment. Otherwise experimental conditions were the same as in the previous study.

Results: The data obtained in this experiment may be summarized in relation to the same variables considered in the previous experimental study.

(1) The Effect of the Steady State Task. The effect of the task on the absolute threshold is shown in Table VIII. It is apparent that the t-ratio, representing the mean task-set threshold difference divided by the standard error of the mean, is significant well beyond the 1% level of confidence. This result is in agreement with those obtained in the previous experiment, run under conditions of zero background noise. In the present study, the subjects did not repeat the same experimental series at weekly intervals.

TABLE VIII

T-TEST FOR SIGNIFICANCE OF MEAN TASK-SET THRESHOLD DIFFERENCE UNDER CONDITIONS OF HIGH NOISE LEVEL

			t. obt.		t required	
M_D	S.D.	$S.E_M$	$D/S.E_M$	df	5% level	1% level
5.893	6.387	0.405	14.55	249	1.972	2.601

TABLE IX

ANALYSIS OF VARIANCE OF TASK-SET THRESHOLD DIFFERENCES: (TWO-DIMENSIONAL TRACKING TASK; HIGH NOISE LEVEL)

Series #1

					F required	
Source of Variance	df	Sum of Squares	Mean Square	F obtained	5% level	1% level
Within Subclasses (Error)	200	9,198.77	45.994			
Frequency (Fr)	4	213.59	53.398	1.161	2.41	
Subjects (S)	9	1,663.09	184.788	4.018**	1.92	2.50
Interaction (Fr x S)	36	1,801.29	50.036	1.088	1.52	
Total	249	12,876.74				

**Significant beyond the 1% level of confidence

TABLE X

ANALYSIS OF VARIANCE OF TASK-SET REACTION TIME DIFFERENCE: HIGH NOISE LEVEL

Series #1

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required 5% level	 1% level
Within Subclasses (Error)	200	22,628,748	113,144			
Frequency (Fr)	4	574,663	143,666	1.270	2.41	
Subjects (S)	9	2,758,754	306,528	2.709**	1.92	2.50
Interaction ((Fr x S)	36	4,705,700	130,714	1.155	1.52	
Total	249	30,667,865				

**Significant beyond 1% level of confidence

(2) *The Effect of Stimulus-Frequency*. The relevant data are presented in Tables IX and X, showing the results of an analysis of variance performed on task-set threshold differences, and task-set reaction time differences, respectively. For both of these possible indicators of attention-demand value, the effect of frequency is not significant, the *F* ratio obtained being below the magnitude required at the 5% level.

(3) *The Effect of Individual Differences*. In both Table IX, relating to task-set threshold differences, and in Table X, relating to task-set reaction time differences, subject variability is found to have a significant effect, beyond the 1% level of confidence.

IV. EXPERIMENTAL STUDY OF THE ATTENTION DEMAND VALUE OF MONOCHROMATIC VISUAL STIMULI AS A FUNCTION OF WAVE LENGTH[1]

A. Special Experimental Conditions

The present experimental study was carried out in the same manner as those described in the previous section, except for changes involved in using monochromatic visual stimuli as the test-stimuli in place of auditory stimuli. A very low level of white background noise was used, just sufficient to mask out slight clicks produced by the shutter used for exposure of the visual stimuli. The subjects wore ear phones, just as in the auditory experiment involving a high level of background noise, but these phones were used only for purposes of communication between the experimenter and the subject prior to an experimental series.

The visual display presented to the subject as a basis for his motor adjustments in the steady state task was identical with that used in the previous experiment, except for one slight change. A small circular white paper disc, 1/2 inch in diameter was attached to the face of the oscilloscope, just over the intersection of the cross-hairs. This small area was, in effect, used as a screen on which a colored beam of monochromatic light was projected from the monochrometer and lens system located behind and slightly to the side of the subject.

The specific wave lengths used to replace auditory stimuli used in previous studies were: 476, 515, 555, 582, and 650 millimicrons. There were five presentations of stimuli at each of these wave lengths, presented in a random sequence, for successive double ramps, just as in the auditory studies, in order to minimize any tendency on the part of the subject to set himself to expect a particular color. In the case of the two ramps presented together to obtain a single instance of a task and a set threshold, the same wave length was used for the entire succession of pulses. This wave length was different, however, in the presentation of the next double ramp, and so on.

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[1] This experiment was carried out with Mr. Leon Asadourian serving as research assistant.

The use in preliminary experimentation, of a small projection area just to the right of the oscilloscope face was found to result in a high degree of variability in the determination of threshold-value. This effect was apparently due to a combination of two factors, the lower thresholds of receptor elements in the periphery of the retina, and the occurrence of intermittent eye movements which might lead the subjects to look toward the "projection area" at the side of the oscilloscope face. The alternative location of the small projection disc directly over the cross-hairs seemed to eliminate this conflict between the subject's tendency to look toward the cross-hairs, in occupying himself with the steady-state task, and any tendency to look at the place where the circles of color were presented. Now both of the possible points of regard were coincident.

Description of the apparatus used in this visual study, and the quantitative specification of the various conditions of interest are given in Appendixes I and II.

B. Results

(1) The Effect of the Task on the Absolute Threshold. In the present study, each subject ran through the experimental series twice, with an interval of about one month between series. Table XI shows the data relevant to the application of the t-test to determine the statistical significance of the mean value obtained for the task-set threshold difference in each of the two series. In Series 1, the mean task-set threshold difference was 17.445 "Brown units," with a standard error of 0.99 and a corresponding t-ratio of 17.61; this lies well beyond the 1% level of confidence.

TABLE XI (Visual Stimuli)

EFFECT OF TASK ON ABSOLUTE THRESHOLD AS INDICATED BY SIGNIFICANCE OF MEAN TASK-SET THRESHOLD DIFFERENCE

Series	M_D Mean Threshold Difference	$S.E_M$	$M_D/S.E_M$	df	t required at 1% level
1	17.448	0.9905	17.61**	274	2.601[1]
2	12.474	0.7632	16.34**	274	2.601

**Significant beyond 1% level of confidence

[1] Required t specified corresponds to a df of 200

In Series 2, the mean task-set threshold difference was 12.4742 Brown units, and the t-ratio 16.34, also well beyond the 1% level of confidence. The task thus has a highly significant effect in raising the absolute threshold of visual stimuli.

(2) The Effect of Wave-Length on the Attention-Demand Value of Visual Stimuli. Tables XII and XIII give the results of an analysis of variance of the task-set threshold differences in Series 1 and 2 respectively. Tables XIV and XV give the equivalent data for reaction time differences.

It will be noted that the F-ratios showing the effect of wave-length (or frequency) on task-set threshold difference are not significant.

TABLE XII

ANALYSIS OF VARIANCE OF TASK-SET THRESHOLD DIFFERENCE: VISUAL STIMULI

Series #1

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required 5% level	F required 1% level
Within Subclasses (Error)	220	51,116.38	232.35			
Frequency (Fr)	4	986.95	246.73	1.062	2.41	
Subjects (S)	10	13,582.78	1,358.27	5.846**	1.87	2.41
Interaction (Fr x S)	40	8,260.04	206.51	0.889	1.55	
Total	274	73,946.15				

**Significant beyond the 1 % level of confidence

TABLE XIII

ANALYSIS OF VARIANCE OF TASK-SET THRESHOLD DIFFERENCE: VISUAL STIMULI

Series #2

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required 5% level	F required 1% level
Within Subclasses (Error)	220	33,358.56	151.63			
Frequency (Fr)	4	1,438.11	359.53	2.37	2.41	
Subjects (S)	10	2,525.11	252.51	1.67	1.87	
Interaction (FrxS)	40	6,566.35	164.16	1.08	1.45	
Total	274	43,888.13				

Similarly, in Tables XIV and XV, relating to reaction-time differences, the obtained F ratios for wave-length or frequency lie below the 5% level of confidence and are not significant. It may be concluded that whether the task-set threshold difference or the task-set reaction time difference is used as an indicator of attention-demand value, the attention-demand value does not vary significantly as a function of wave-length, within the range of wave-lengths considered, and under the particular experimental conditions involved in the present study.

It may be noted that the independent variable here may be referred to either as wave-length or frequency, since the frequency is inversely proportional to the wave-length, being equal to the reciprocal of the wave-length multiplied by the speed of light.

TABLE XIV

ANALYSIS OF VARIANCE OF TASK-SET REACTION TIME DIFFERENCE: VISUAL SERIES

Series #1

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required 5% level	F required 1% level
Within Subclasses (Error)	220	17,675,490	80,343			
Frequency (Fr)	4	90,227	22,557	0.28	5.65	
Subjects (S)	10	4,981,470	49,815	0.62	2.56	
Interaction (Fr x S)	40	4,171,902	104,298	1.30	1.45	
Total	274	26,919,089				

TABLE XV

ANALYSIS OF VARIANCE OF TASK-SET REACTION TIME DIFFERENCE: VISUAL SERIES

Series #2

Source of Variance	df	Sum of Squares	Mean Square	F obtained	F required 5% level	F required 1% level
Within Subclasses (Error)	220	14,460,689	65,730			
Frequency (Fr)	4	401,776	100,444	1.528	2.41	
Subjects (S)	10	1,544,955	154,495	2.350*	1.87	2.41
Interaction (Fr x S)	40	2,818,799	70.469	1,071	1.45	
Total	274	19,226,219				

*Significant beyond the 5% level of confidence

(3) Subordinate Factors

(a) Individual Differences. Examination of Tables XII through XV, representing analysis of variance, shows that the subject-variable had a significant effect on the task-set threshold difference in Series 1 but not in Series 2. In the case of the task-set reaction time difference, too, there is a significant effect of subject variations in Series 2, at the 5% level, but not in Series 1.

Examination of the effect of the treatment interaction, of subject with frequency, shows it not to be significant either for threshold differences, or reaction time differences, either in Series 1 or 2.

(b) The Effect of Repetition of the Experimental Series.

In the present study, too, we find that repetition of the experimental series has a consistent effect, at all wave lengths, on the size of the mean task-set threshold difference. As is indicated in Table XVI, the magnitude of this difference decreases at all wave lengths. An examination of Table XVII, giving the corresponding information for task-set reaction time difference, shows that the effect is not so consistent here. There is a decrease in the mean-reaction-time difference at three wave lengths, but an increase at two other wave lengths. In the next section, dealing with a general discussion of our results, statistical data bearing on the statistical significance of this "habituation-attention "effect will be presented.

TABLE XVI

THE MEAN TASK MINUS SET-THRESHOLD DIFFERENCE[1]
AS A FUNCTION OF WAVE-LENGTH AND SERIES

Series	476 mμ	515 mμ	555 mμ	582 mμ	650 mμ
1	15.2	20.8	18.0	16.7	16.4
2	9.7	15.3	15.1	10.4	12.0
Difference	5.5	5.5	2.9	6.3	4.4

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[1] The threshold difference is given in terms of "Brown Units", the units on the Brown strip chart recorder used.

TABLE XVII

THE MEAN TASK MINUS SET REACTION-TIME DIFFERENCE[1] AS A FUNCTION OF WAVE-LENGTH AND SERIES

Series	476 mμ	515 mμ	555 mμ	582 mμ	650 mμ
1	85.4	105.7	91.9	60.2	55.9
2	55.9	72.8	130.3	88.3	13.8
Difference	29.5	32.9	-38.4	-28.1	42.1

[1] Reaction-time difference is given in milliseconds.

V. DISCUSSION

In this section, we may consider questions which might have been discussed in connection with several of the individual experimental studies but which are collected here for reasons of brevity.

A. Concerning the Validity of Methods of Measuring Attention-Demand Value

The present investigation has been concerned with the development of a more effective method for measurement of the attention-demand value of stimuli, and its application to determining, in the modalities of audition and vision, whether variations in stimulus-frequency play a significant role.

The special method developed was one based on the concept of the absolute threshold, but with a special procedure fashioned to permit determination, in rapid sequence, of a threshold determined while a subject is engaged in a task (the task-threshold), followed by one while a subject is set to expect the stimulus (the set-threshold). The difference between these two thresholds, in decibels, was proposed as an indicator of attention-demand value. If set-threshold is subtracted from task-threshold, we have a measure of the increase in absolute sensory threshold resulting from the subject's absorption in a task. The size of this increase can be considered inversely proportional to the attention-demand value. To make the relation direct rather than inverse, the algebraic sign of the difference may be reversed, and we have a measure whose level, when graphed, should change directly with the attention-demand value.

Now the question may be raised whether this method of measuring attention-demand value should be considered a more valid method than others that have been proposed. We do not consider it feasible to arrive at any decisive answer to this question at the present time. All that we should contend would be: first, that it is a different type of method than others that have been proposed, therefore one that increases resources we have available for measuring the attention-demand value of stimuli; second, that it rests on a type of approach to measurement of stimulus-effectiveness that has been regarded as fundamental in other areas, such as the neural and sensory; and third, that we have found in the present investigation certain lines of evidence which support the doctrine that it may be considered a valid method, (principally the evidence that the task produces a highly significant increase in the absolute sensory threshold).

There is no direct and easy way to compare the validity of this method with other methods, since we have no established method of measurement which can be regarded as capable of providing, under all conditions, valid and objective measures of attention-demand value of stimuli, measures that can be used as standards in determining the validity of the present method. At some later time, when more experience has been accumulated from attempts to apply the present method, it may be appropriate to systematically compare it with previously described methods from the point of view of validity, reliability, convenience and the situations for which it is suitable.

If one inquires concerning the particular need for using a difference between two thresholds, a task and a set-threshold as an indicator of attention-demand value, it must be granted that it is a procedure especially designed to reveal the special role of stimulus-frequency in attention-demand value.

It is well known that different stimulus frequencies differ in their effectiveness in eliciting perception, even when a subject is not engaged in a task, but is set for the stimulus. Such differences are conventionally attributed to differences in receptor-sensitivity. Consequently, even though our objective, in obtaining a measure of attention-demand value, is to compare different stimuli in effectiveness when a subject is engaged in a task, it seemed necessary to exclude effects due to receptor-sensitivity as such. This was on the assumption that there might be a difference. Since the receptors are necessarily involved even in the determination of task-thresholds it seemed that there was no way of excluding the special effects of receptor dependence on frequency, other than by a computational procedure. The procedure of obtaining an attention-demand indicator by explicitly taking the difference between task and set thresholds was thus a device dictated by our interest in the role of stimulus-frequency.

In case, however, one were interested in conditions other than stimulus-frequency as a condition of attention, it would probably be desirable to reexamine the question of the most appropriate quantitative indicator. For other conditions, it might be acceptable to use the task-threshold itself, rather than to use this magnitude after the set-threshold has been subtracted from it. Thus, in an investigation to determine whether a single pulse or a repeated pulse is more attention-demanding, at the same stimulus-frequency, it would seem feasible to use the task-threshold values themselves as a basis for comparison. But except for appropriate changes in the make-up of the series of experimental test-stimuli, a threshold-method such as developed in the present study would still be appropriate.

B. Concerning the Effect of Stimulus-Frequency on Attention-Demand Value

The principal experimental goal of the present investigation was to determine whether the attention-demand value of a stimulus is a function of stimulus-frequency, in the modalities of audition and vision. The results seem quite decisive when we consider the number of groups examined and the range of frequencies sampled in these two modalities. In no one of the four experimental studies was a statistically significant effect of frequency obtained. This was true for both indicators of attention-demand value examined, (1) for the task-set threshold difference, which provided our principle technique, especially fashioned for this investigation, and (2) for the task-set reaction time difference, based on a more traditional technique for measuring attention- demand value.

Despite the uniformity of these results, the point might be made that if there were a non-linear relationship between attention-demand value and frequency, (if, for example, one specific frequency had an attention-demand value greater than any of the others) this effect might not show up with the statistical technique used here. It might be pointed out, for example, that the analysis of variance technique as used here involves a pooling of effects at all the different frequencies and that this pooling might result in an obscuring of the difference existing between some one frequency and all the others.

To test this possibility, the following supplementary procedure was carried out in several of the experimental studies with respect to the task-set threshold. The mean value of this threshold difference was examined at all frequencies, to determine the frequency with the smallest task-set difference. The data for all the other frequencies were pooled, and F-ratio computed to determine whether the minimum task-set threshold difference (taken as indication of greater demand value) was significantly different from the mean of all the other frequency groups combined. The results of this analysis are shown in Table XVIII. In no case was a significant F-ratio found. This test, then, fails to give evidence in any of the three studies of a particular frequency with an attention- demand value significantly greater than the mean level of the other frequencies in the range examined.

What, now, are the practical implications of this failure to find a significant effect of stimulus-frequency on attention-demand value, or some one frequency of significantly greater attention-demand value than the rest? The question can be more adequately answered if we reexamine the indicator of attention-demand value utilized in these studies, and its relation to practical problems. We have been using as our chief indicator the difference in task and set thresholds in order to determine whether different stimulus-frequencies show differences in attention-demand value over and above that attributable to the sense organs. We find that they do not. This prodecure of attempting to separate the effect of sensory structures from other mechanisms in the organism is one that seems appropriate from the point of view of general psychology, with its emphasis on analysis. But if one is faced with the need of proposing specific kinds of stimuli to be used as warning signals in practical situations, then it may be more meaningful to drop this distinction between the variation in threshold with frequency that is due to the sense organs, and that which is due to supplementary structures that become operative when a subject is engaged in a task. From this point of view, we might simplify our question and merely ask: Is there a difference in the effectiveness of different frequencies of stimulus in bringing about perception of the stimulus when a subject is engaged in an absorbing task? In effect, we are asking how the task-threshold varies as a function of stimulus-frequency. The findings reported for the various studies suggest a rather decisive answer. Stimuli do vary in their effectiveness in attracting attention, but their relative effectiveness is the same whether the subject is engaged in a task, or set to perceive the stimulus. In short,

TABLE XVIII

Summary of Analyses of Variance Carried out to Determine Whether the Stimulus-Frequency with Maximum Attention Demand Value (Minimum Task-set Threshold Difference) is Significantly Different In Threshold Difference from the Other Frequency-Groups Combined

Sense Modality	Source of Variance	df	Sum of Squares	Mean Square	F obt.	F req. at 5% level
Audition (zero noise background)	Between freq. groups (3000 vs. all others)	1	27	27.	0.76	
	Within subclasses (error)	200	7,077	35.387		
Audition (high noise background)	Between freq. groups (2000 cycles vs. all others)	1	76	76.	1.65	3.89
	Within Subclasses (error)	200	9,198	45.994		
Vision	Between freq. groups (476 mu vs. all others)	1	337	337.	1.45	3.89
	Within subclasses (error)	220	51,116	232.		

the visibility curve in vision, and the audibility curve in audition can be used to represent the over-all attention-demand values of stimuli.

Persistent attention to a task on the part of the subject does not, on the basis of our findings, alter the relative effectiveness of these stimuli. In a given practical problem, other considerations than stimulus-effectiveness must no doubt also be considered in the final choice of signals to be used. But as far as this one attribute of a stimulus is concerned - effectiveness in eliciting perception when a subject is engaged in a task; an attribute which we might designate as "over-all attention-demand value" - the results indicate that the reciprocal of sensory-threshold curves may be used to show relative values.

C. Some Further Comments on the Method and Its Possible Extension

(1) Concerning the Importance of Randomization of Successive Stimuli. An unavoidable requirement in the development of a threshold method for measuring attention-demand value seemed to be the maintenance of the subject's attention on the steady-state task, up to the instant that he perceived a test-stimulus, and the avoidance of any attitude of looking for or listening for a stimulus. The latter procedure would mean that the threshold obtained would in reality be a set-threshold rather than a task threshold. The fact that the task-thresholds obtained showed such a highly significant difference from the set-thresholds indicates that the procedures adopted were effective. One feature of these procedures that probably contributed considerably to their effectiveness was the practice of randomizing successive stimuli in frequency. It seems likely that a desirable feature in any future use of the present method, even in studies in which the effect of stimulus-frequency is not of interest to the investigator, will be this procedure of presenting a multiplicity of different frequencies in random order. In the present study it was suggested by the need of determining the effect of different frequencies, but in other studies its importance will lie in the fact that randomization of the frequency of successive stimuli, (when it results in corresponding qualitative differences in the subject's experience) makes it impossible for the subject to get set for any specific quality, and thus makes it easier for him to maintain his attention on the task

itself. To check the desirability of this feature of the method, it would be of interest to perform an experiment in which a stimulus of the same frequency (quality) was presented in successive pairs of ramps, and to compare the size of the mean task-set threshold differences obtained under these conditions with those resulting with the randomization procedure followed in the present investigation.

(2) The Presentation of Both Auditory and Visual Stimuli in the Same Experimental Series. The need for a wide variety of signals in modern aircraft makes it natural to consider incorporating stimuli from more than one sense department in the same system of signalling. The question may be raised whether such a procedure might have an adverse effect on the probability of any particular signal being perceived by the subject. The question was suggested by the way our apparatus is set up for presentation of auditory or visual stimuli. By a simple switching arrangement it would be possible to include both visual and auditory stimuli of different frequencies in the same experimental series, and to determine whether the task-threshold for a particular type of stimulus, for example, auditory stimuli, is increased due to the fact that visual test-stimuli (or warning signals) are included in the same experimental series. An investigation of this sort may be of value both for methodological reasons, as a technique for increasing the size of task-set threshold differences for investigative purposes, and for practical reasons, to determine the advisability of mixing two modalities of signal in the same initial warning system. An increase in the mean task-set threshold difference for stimuli in either sense department, due to the presence in the same series of stimuli from another sense department, would have to be regarded as a decrease in attention-demand value.

D. A "Task-Habituation Effect", as Indicated by the Magnitude of Task-Set Threshold Differences in Repeated Series

In two of the experimental studies provision was made for the replication of the experimental runs by each subject: at intervals of a week, in auditory study; and of more than one month, in a visual study. In both of these studies, examination of the curves showing mean task-set threshold difference as a function of stimulus-frequency for each of the successive periods, indicates a definite decrease in the magnitude of the task-set threshold difference with later series. For want of a better term, we may designate this effect as a habituation-effect. The change may be attributed, by way of hypothesis, to the habituation of the subject to the task (associated either with an increase in skill, or a reduction in the strength of motives), which leads him to exert less effort, and consequently to give less attention to the steady state task. Such a change in the subject's attitude to the task might be expected to result in a reduction in the level of the task-set threshold difference for the entire curve.

An estimate of the statistical significance of this effect might be obtained by computing a mean value of the task-set threshold difference for each replication series, and deriving a t-ratio to test significance of the differencebetween each series and the immediately preceding series. These data are assembled in Table XIX. It is apparent that this habituation effect is significant in both the auditory and visual study, with the t obtained significant beyond the 1% level of confidence.

E. Individual Differences in Task-Set Threshold Difference and Relation to Other Traits and Capacities of the Individual

As has been pointed out in the statement of results, significant differences among individual subjects, in the size of the task-set threshold difference, were found to occur in every experimental study. The possible implications of this result for method have been mentioned. If subjects could be selected on the basis of a tendency to large task-set threshold differences, and small variances under a given set of conditions, it might be possible to obtain experimental groups that might be more suitable for investigating the effects of special factors, such as frequency, than are groups in which all available subjects are accepted. Particularly in problems such as the present one, in which rather stringent demands are made on the subject, there seem no satisfactory bases for assuming that all subjects are equally appropriate for obtaining answers to the questions of interest.

The finding of marked differences in the size of task-set threshold differences among individual subjects suggests also that such differences might be related to other traits of capacity or personality of the individual that may be important in practical situations. Thus a large task-set threshold in a given subject might indicate an individual with a capacity to give a greater

TABLE XIX

THE STATISTICAL SIGNIFICANCE OF THE HABITUATION-ATTENUATION EFFECT

Sense Modality	Replication Series Compared	Decrease in Mean (task-set) Threshold Difference[1]	S.E. of Difference	df	t D/SE	t req. at 1% level[2]
Audition (zero noise)	2 with 1	1.97 db.	0.4640	498	4.246**	2.588
	3 with 2	1.52 db.	0.4327	498	3.513**	2.588
Vision	2 with 1	4.97 Brown units	1.2490	548	3.982**	2.588

[1] This decrease is computed by subtracting the mean task-set threshold difference of the later series from the mean of the earlier series.

[2] The value given for required t corresponds to 400 degrees of freedom, a value smaller than the df involved in the present studies.

**Significant beyond the 1% level of confidence

degree of attention to a task than a subject with a small threshold difference. Such differences might in turn be correlated with differences in ability to acquire difficult skills and to solve difficult problems, assuming equivalence in intelligence.

Similarly, the extent to which the task-set threshold difference of an individual fluctuates irregularly as a function of time may provide a quantitative measure of "vigilance" or the "stability of attention" given to a task. Such traits would also be expected to play a role in the aptitude of individuals for tasks requiring sustained attention.

Future correlational studies along these lines might thus be of value in providing additional techniques to aid in the selection of personnel suitable for training for difficult skills as well as in helping to monitor the effectiveness of training procedures.

VI. SUMMARY AND CONCLUSION

As a basis for the selection of stimuli suitable for use as warning signals when an individual is engaged in a task, the question was raised of possible differences in effectiveness of different stimuli. Following a survey of the literature, a method was developed which was intended to provide a laboratory analogue of tasks in which subjects might be engaged, and which lent itself to measurements of stimulus-effectiveness in attracting the attention of the subject. Quantitative measures could now be obtained both by threshold techniques and reaction-time techniques.

Comparison, by these procedures, of auditory stimuli differing in frequency, and of visual stimuli differing in wave length, under different conditions of background noise, showed that: (1) attention to an absorbing task results in a highly significant increase in the absolute threshold of all stimuli, but not in their reaction-times, (2) differences in stimulus-effectiveness as a function of differences in frequency or wave-length, when an individual is engaged in a task, parallels the differences found when he is not engaged in a task: the increase in the stimulus threshold resulting from the subject being engaged in a task does not change significantly with the frequency of the stimulus, (3) subjects differ significantly from each other in the extent to which a task increases their absolute thresholds, and (4) a fairly marked attenuation in the increase in threshold associated with a task occurs upon replication of the experimental series, pointing to the existence of task-habituation effects.

With respect to the practical problem of designing systems of warning signals, these results indicate that engineers and engineering psychologists are justified in utilizing the substantial body of knowledge already established concerning sensory thresholds, and their dependence on frequency, as a guide in the selection of stimuli to be used as warning signals. No statistically significant change in the form of sensory threshold curves results from distraction of the individual by a task.

The findings with respect to individual differences and the attenuation effect suggest the relevance of the type of measurement made in this investigation to psychological problems of importance in other areas, such as the selection of personnel for skilled tasks and the measurement of changes in effort in the course of tasks requiring sustained vigilance. Possible directions of research along these lines are indicated.

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APPENDIX I

APPARATUS USED FOR STEADY STATE TASK

The provision of a steady state task to which the subject can be induced to give a high level of sustained attention is an important feature of the double ramp method described earlier. A learning task involving continuous tracking was fashioned to meet this requirement. It involved the organization of a fairly complex system of pieces in order to make the operation automatic. Automation seemed necessary due to the multiplicity of separate events affecting the subject and the need of conforming to a special time schedule, both in the steady state task itself, and in its relation to the presentation of the patterns of test stimuli used in the determination of thresholds.

The overall operation of this system is most easily described by reference to the block diagram of Figure 3. This should be examined along with the description given below.

A. Pieces Controlling Target-Pattern

The Function Generator and Control Stick are essentially alike. Each consists of a joy stick mounted so as to be free to move easily relative to two axes of rotation at right angles to each other. The subject's control stick has potentiometers[1] (potential dividers) mounted on each axis so that the contact wiper moves from its center-position as the stick moves from the vertical position. One pot may be designated as the x-pot, and the other as the y-pot. A supplementary feature is the mounting of a surface cam on the bottom of the stick.[2] This cam is used to actuate, by appropriate links, a third pot mounted below the cam. The cam is shaped so that the change in resistance of the pot relative to the

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[1] In accordance with convention, we shall, for brevity, refer to a potentiometer by the conventionally used term Pot.

[2] The idea of using a surface cam at the bottom of the subject's control stick to correspond to its angle was suggested by Mr. Senders, of the Aero-Medical Laboratory.

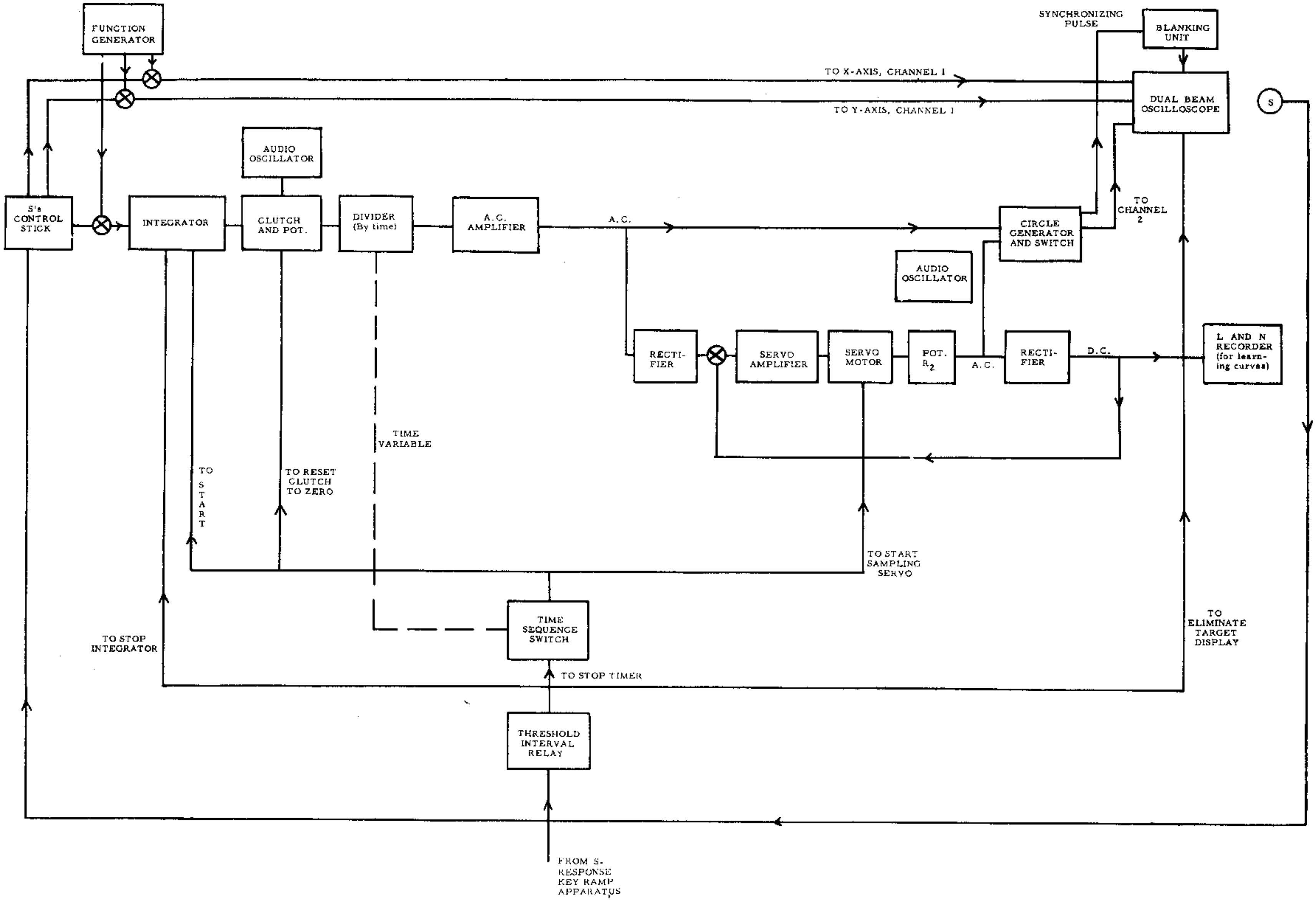

Figure 3. Block Diagram of Equipment Used in the Display and Measurement of Performance in the Steady State Task. (Intersecting Lines Are Not To Be Regarded as Junction Points Unless Point Is Indicated by Solid Circle).

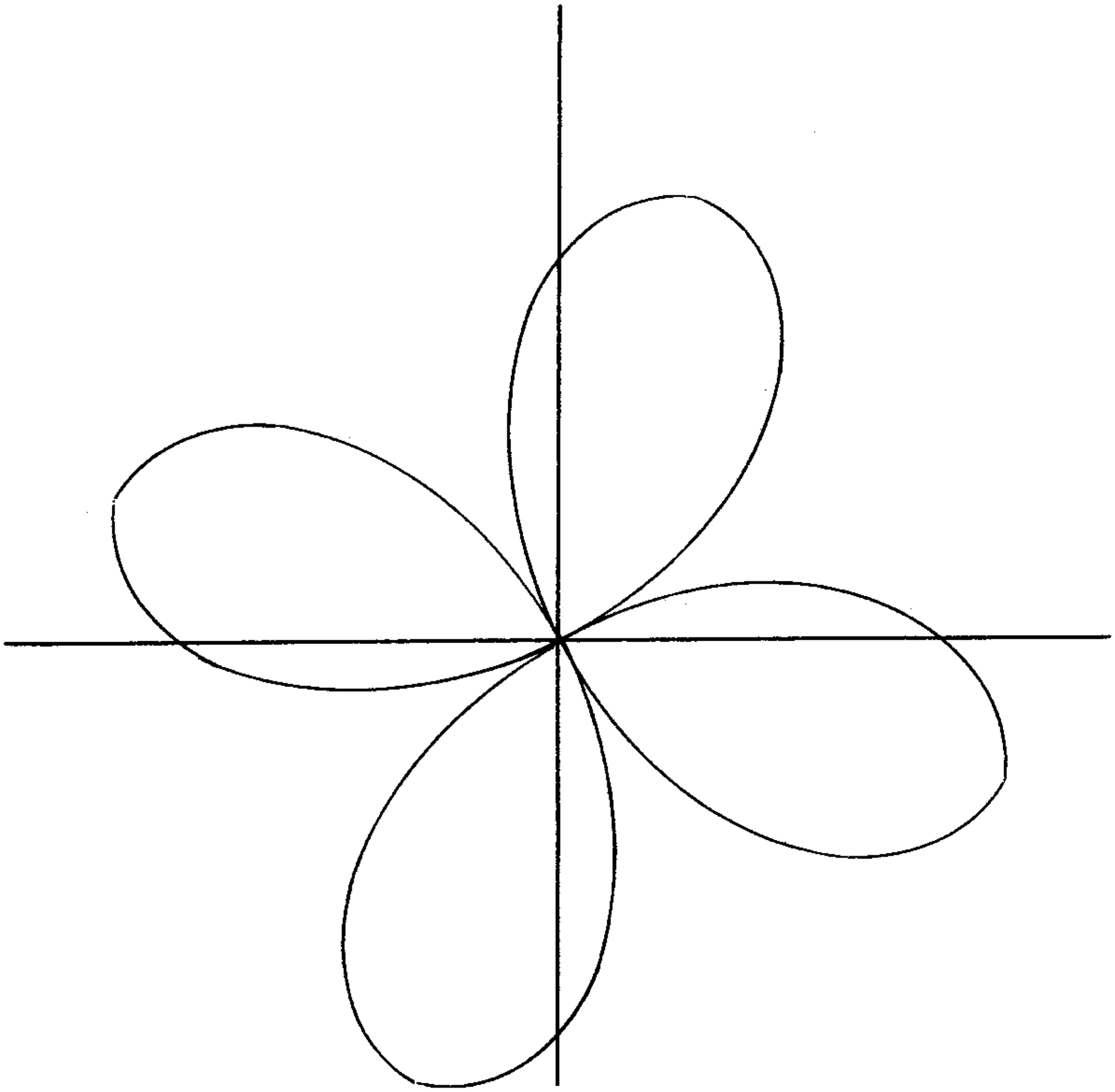

Figure 4. The "Input" to the Subject-Compensatory Tracking System: The Pattern Traced by the Spot on the Oscilloscope Screen in the Absence of Compensation by the Subject

center-position taken as zero, is proportional to the angle of movement of the stick, regardless of the plane in which the stick moves. This arrangement provides a mechanical way of obtaining a direct measurement of the angle of stick movement without the necessity of combining the measurements taken from each of the coordinate pots (x-pot and y-pot) mentioned above.

The function generator is a second stick, also normally vertical, equipped with an identical set of three pots. We may designate them as the x, y, and z-pots, the latter referring to the pot associated with the surface cam provided to measure angle independently of plane of movement.

The actuation of the function-generator stick is accomplished by means of two cams, each driven by a separate motor. The stick, above its pivot, moves in a slot in a plate. One of the cams determines, at any instant, the angle of this slot in a horizontal plane and the other cam, the deviation or position of the stick in the slot. If the two z-pots are connected in parallel with each other and a D.C. power source (200 volts), then the p.d. between the wiper contacts will provide a measure of the difference in angle of the two sticks, in accordance with a familiar arrangement of pots used in error-detection in servo systems. The same arrangement is used to connect the pair of x-pots and the pair of y-pots, each pair being independent of the others.

The error-voltage obtained from the x-pots is applied to the x-axis of one channel of a C.R. oscilloscope; that from the y-pots to the y-axis of the same oscilloscope channel, and that from the pair of z-pots to measuring equipment designed to obtain a tracking-score for the subject. As a result of this arrangement, the movements of the oscilloscope spot will exactly follow the angular deviations of the subject's control stick, in the correct directions relative to the center; and yet we are able to obtain a measure of the vector-distance from the center of the oscilloscope screen to the oscilloscope-spot without the necessity of a computer to obtain the square root of the sum of the squares of the x and y voltages. This direct measure of a quantity proportional to the vector magnitude is provided by the error-voltage obtained from the pair of z-pots.

The time pattern of spot movements produced on the oscilloscope, with the subject not attempting to compensate, is shown in Figure 4. The amplitude can be set independently by the x and y gain controls of the oscilloscope. This pattern is initiated during an experimental period by the closing of the switch controlling power to the two cammotors. At the same time, the power switch to the ramp time-sequence programmer in the threshold equipment is closed, to initiate the time sequence for the test signals. The actual time pattern seen by the subject on the oscilloscope face will of course depend on his own compensatory movements, and cannot be known ahead of time.

The diagram in Figure 3 shows the signals from the x and y pairs of pots going directly to the x and y input terminals of one channel of the oscilloscope. The resultant pattern is what is actually used by the subject to guide his adjustments. What appears as a result of the signal applied to channel two can affect only the degree of effort and attention given by him to his task, and not the specific compensatory movements.

B. Equipment for Measuring Subject's Average Error Score

The p.d. between the wipers of the pair of z-pots can be regarded as representing S's instantaneous error and is proportional to the deviation of the scope spot from the cross-hairs. In treating this value as our index of error, we are ignoring the angular position of the spot relative to the center.

(1) The Integrator. The z-signal is first sent through a rectifier (not shown in diagram), to eliminate any differences in polarity, and then sent through the integrator, the output of which is a voltage proportional to the time integral of the rectified instantaneous error. The integrator finally selected for use in the main series of experiments is a servo-system type of integrator. It was adopted due to its being less subject to random variations than an electronic type integrator that was tried initially, as well as on account of the ease with which it was possible to provide certain memory functions to be mentioned later. This integrator is essentially a rate servo-system, the rate of the motor shaft being proportional to the input voltage. Consequently the angular position of the motor shaft, which is the integral of its rate, will also be proportional to the integral of the input voltage. By connecting a pot to the motor shaft, the angular position is easily converted into a voltage. The voltage can easily be made A.C. or D.C. depending on the type of voltage source connected across the integral pot. We used A.C. since we are enabled thereby to avoid using a modulator at a later point. An audio oscillator set at 2000 cycles was used to provide the A.C.

A clutch controlled by a solonoid is located between the pot and servo-motor shaft so that the pot, and therefore the voltage representing the integral of the error, can be returned to its zero position at any time simply by energizing the solonoid. In our experiments, such resetting to zero was brought about at one minute intervals, in order to obtain a score for the subject that could be sampled frequently throughout the experimental period. It will be noted in the diagram that a timer (controlling the sequence of closing or opening of a set of switches) controls the clutch-solonoid. The timer is driven by a synchronous motor, which in effect controls the actuation of switches by means of cams.

We were interested in the subject's error-score over an interval for two reasons, (a) to record the progress subject made acquiring tracking skill during an experimental period, and (b) to feed back this information to him in the hope of motivating him to try harder, expecting that such effort would be associated with an increased level of attention to the steady state task. Since we wished him to have his present error-score continuously available as a spur to tracking effort, it was not felt to be satisfactory to use the one minute integral as an index quantity, since this integral, being cumulative in character, would change throughout the course of the integration period, even if subject were operating at the same level of skill. An effort was therefore made to obtain a continuous average error. Mathematically, this could be done simply by dividing the integral of the error by the interval of the time over which the integral was taken. That is

$$\text{Average error} = \frac{\int_o^t \xi \, dt}{t} \qquad (1)$$

where ξ is the instaneous error,
and t is time.

(2) The Divider. Eq. (1) indicates that we might obtain a quantity to represent the average error if we could, by means of a computer, divide the voltage output of the integrator by a quantity that would grow linearly with time from the beginning of the integration period. This was accomplished by placing a 20,000 ohm variable

resistance in series with the integrator voltage and regarding the current as the quotient of the integral divided by time. This current was in turn converted into a voltage drop across a small resistance (10 ohms). The divider circuit thus consists simply of the integrator pot, the variable divider-resistance, and a small fixed resistance (for converting current to voltage), all in series. The variable resistance was made to change, in proportion to time t, by modifying the timer so that its synchronous motor would drive the variable resistance. A one-rpm motor was used in the timer so that one cycle of operations of the timer would be synchronized with the maximum period to represent t. Thus the integrator voltage and the dividing resistance representing t were both zero at the beginning of every new integration interval of one minute. Mechanical coupling of the timer motor and the divider resistance is indicated in Figure 3 by the broken line.

(3) The Circle Generator. The A-C amplitude representing average error (the A-C Source consisting of an audio oscillator set at 2,000 cycles connected across the integrator pot) could now be made to provide a circle on the oscilloscope, the diameter of which would be proportional to the average error. To provide the necessary signals to establish a circle on channel 2 of the CRO, the A-C signal was sent into the circle generator. This consisted of two R-C phase shifting networks connected to a Stevens-Arnold millisecond switch. The output of one of the phase-shifting networks was two A-C signals, equivalent in amplitude, but 90° out of phase with each other. Connected to the x and y inputs of an oscilloscope, these two signals produce a circular trace proportional in radius to the amplitude of the signal in volts. As the amplitude changes in time with the average error, the radius of the circle changes concurrently. The subject will, therefore, in the perception of this circle, have an index of the magnitude of his average error score.

(4) The Sampling Servo-System. In order properly to motivate the subject, it seems necessary that he be given information not only of his present level of performance, but some standard that he may strive for, and with which he can compare his present level of performance. In terms of servo-system concepts, he must be presented with a set point in addition to a record of his output. We initially considered using static circles drawn on the face of the oscilloscope to provide him with standards with which he might compare present performance. This plan was dropped, however, on the basis of studies of McGuire in the early stages of this project

in which it was found that static circles of different size did not produce significant effect in determining the performance of subjects in a two-dimensional compensatory tracking task.

An alternative type of set point that was considered as a basis for providing stronger motivation than fixed error-circles was that of allowing the subject to provide his own standards, based on his performance earlier in the experimental period, when he had been urged to try as hard as he could. But here, too, it seemed desirable to avoid fixed standards, since it seemed reasonable to expect that as his level of skill increased throughout the period, the effort required to exceed some fixed level of performance established initially would become less. What was needed was some set point that would change as his skill increased, and which might thus keep the subject at a high and relatively constant level of effort. This idea suggested the possibility of taking as a set point the subject's level of performance at some earlier time in the period, but allow-in the sample selected to establish the set point to move progressively forward in time as the duration of his practice increased. Thus what was needed was a memory device which would retain a record of the subject's performance a certain interval of time earlier than the present moment, and simultaneously present him with this information.

This result was accomplished by means of the sampling servo-system represented in the diagram at the next level below the integrator-divider units. The first step was changing the A-C to D-C by means of a rectifier-filter unit. This signal went in turn through an amplifier, and motor, which was coupled to a pot. Connected across this pot was a second audio-oscillator. The A-C output of the pot would therefore vary with the position of the pot-contact. This A-C was then rectified and compared by means of the feed-back link with the A-C output of the first rectifier. The servo-motor when connected would move the pot contact until the input and output D-C were equal. Consequently, the A-C input to each rectifier would also be equal in amplitude, since the transfer constants for the two rectifiers were equal. Now, if the servo-motor circuit were closed only briefly at the end of the one-minute integrating intervals, just prior to the resetting of the integrator clutch, then the output of pot R_2 during the subsequent interval would correspond to the subject's average error at the end of the previous integrating period. The sampling servo-system, taken in conjunction with the fixed position of the pot contact when the servo-motor was disconnected, would provide us with the desired memory information.

The A-C signal from pot R_2 could now be applied to a second phase shifting network in the circle generator, to provide the second pair of A-C signals required for producing the trace of a second circle on the oscilloscope. One difficulty arises, however. The signals corresponding to the first circle, representing the present average error score have already used up the available beams or channels on the dual beam oscilloscope. Consequently, it was necessary to use a switch, the inputs to which consisted of two pairs of signals,-the pair representing the continuous average error, and the pair representing the "remembered" average error of the previous sampling instant. The output of the switch was connected to the second channel of the oscilloscope. The subject would thus see two circles, each of which was perceived as having continuous contours.

(5) Blanking Unit. One technical defect was noted. There was often a considerable amount of "hash", stray lines on the oscilloscope face, presumably associated with transient contact-effects in the switch. To eliminate these undesirable visual effects in the display, a blanking unit was made up from Tektronic pulse generator components which blanked out the beam of oscilloscope channel 2, at the moments when the transients appeared. A synchronizing pulse, transmitted from the switching unit to the blanking unit, is adjusted for maximum elimination of transients.

(6) Recorder for Tracking-Score and Learning-Curve. To provide a record of the subject's performance throughout the period, a Leeds and Northrup strip chart recorder, modified to permit driving the paper chart by means of an external gear train and motor, could be connected to a D-C output representing either present continuous average error-score, or intermittent average error-score, as sampled at one-minute intervals. The record thus obtained provided the subject's learning curve without further plotting. In the beginning of any experimental period, an important feature of the procedure for motivating the subject consisted in demonstrating this recording equipment to him, and pointing out the nature of the learning record that would be obtained. He was shown the records of other subjects and told that at the end of the period he would be able to compare his own performance with that of the others. Thus, various subterfuges were used to get him to believe that the aim of the study

was to determine how individuals differed in their rate of learning, and to determine the maximum rate possible. Other details in the instructions to the subject are given in the published paper on the method. The recorder could be connected to any one of several points for the purpose of obtaining a record of the learning curve. In the present series of studies, it was connected to the output of the sampling servo, since the trend associated with learning was more clear-cut in these records, and hence more easily demonstrated to the subjects.

This completes the description of the units involved in measurement and display of signals in the steady-state task. Two additional pieces are shown in the lower part of the diagram. These may now be considered.

(7) The Time Sequence Controller. The time sequence controller has been mentioned. It determines the time in each integrating period at which the following events occur: (a) the start of the integration servo-motor, coincident with the start of the cycle, (b) the instant, just before the end of the one-minute period, when the continuous average error score is sampled, and (c) the actuation of the clutch solenoid to reset the integrator voltage to zero. The time sequence controller also provides the motor for driving the dividing resistance. The power supply for this motor is connected to a pair of contacts in the threshold interval-relay so that when the subject responds to a pulse in the first ramp, actuation of the subject-relay will bring about a stopping of the time sequence controller until S responds to a pulse in the second ramp.

(8) The Threshold Interval Relay. This unit functions to bring about two effects in the interval between the S's response to the initial member of any pair of ramps, and his response to some pulse in the second ramp of a pair. The first response signalizes his perception of the warning signal. He has been instructed that immediately following his pressing of the key as an indication that he has heard the warning signal, he should stop tracking and listen for a signal similar to the warning signal in pitch (or color) to occur again. During this interval it was found to be desirable to eliminate the changing pattern associated with the visual display, as well as to stop processes relating to measurement.

It was found necessary to eliminate the display, since when left on during the interval in which the subject was instructed to listen for the stimulus, it was found to act as a distracter, and subjects found it difficult to "concentrate" on the expected stimulus. There was thus danger that the measurement of set-threshold would be in error.

It was felt necessary also to interrupt the measurement of tracking error in order to avoid giving subjects any occasion to doubt the explanation we had given them of the purpose of the experiment. If we had continued to compute an error score even in intervals when they were not expected to be tracking, it would have been natural for them to be suspicious of our statements.

The threshold interval relay is a latch type of relay that is energized by the closing of the subject-response relay of the threshold-measuring system. When the coil is energized by a momentary pulse, all contacts in the secondary are changed, and then held in the same state, due to the action of a ratchet device, until a second pulse is received from the subject-relay of the threshold-measuring system. This second pulse returns all the circuits which had been altered back to their original condition. Since the first pulse is received when S presses his key to indicate that he has perceived the warning signal, and the second pulse when S presses the key a second time, to indicate he has perceived a second tone-pulse, the intensity of which is taken to represent his set-threshold, the interval between the two pulses is the interval during which S has been instructed to listen for the test-stimulus, and during which he has been instructed to stop his tracking activities.

The threshold-interval relay is wired up so that the following effects are produced when this relay is first energized: (a) A relatively large fixed voltage is applied to the input of the first channel of the C.R.O., so that the target-spot being tracked is thrown off the screen; (b) the motor of the integrator-servo is disconnected so that the integrator pot remains stationary at its last position; and (c) the sequence timer is stopped so that the cycle remains fixed at the point it was when S pressed his key. The stopping of integration, together with the stopping of the synchronous motor of the timer, which controls the divider-resistance, means that the circles on the C.R.O. face cannot change until the subject has finished listening for the test-signal. The display screen thus becomes static and there are no changes to distract the subject. Also, the stopping of the timer means that no part of the measuring period will be lost during the time S is listening to the stimulus, and that a full minute of tracking will go into every measuring period.

APPENDIX II

APPARATUS USED IN DOUBLE RAMP METHOD FOR MEASUREMENT OF THRESHOLDS

A. Auditory Stimuli

A block diagram of the system is given in Figure 5. The top row of the diagram shows the units used in controlling the frequency, intensity and time characteristics of the auditory test-stimuli.

(1) Oscillator. The oscillator was a General Radio type 1304A Beat Frequency audio oscillator. It provides a range of sinusoidal electrical oscillations with less than 0.25% distortion, in the frequency range from 100 to 20,000 cycles per sec. and output voltages which vary less than 0.25 db in the frequency range from 20 to 20,000 cycles.

In use during a given experimental study, the intensity dial on the oscillator was left fixed at the maximum value to be used in the experimental series. The frequency dial was set by the experimenter immediately following the end of each double ramp, so that conditions were in readiness for the presentation of the next double ramp, at a time determined by the programming tape.

(2) Exponential Attenuator. The next unit may be designated an exponential attenuator. It modulates the amplitude of the sinusoidal oscillations in such a manner as to produce a sine wave of amplitude which increases from zero to close to the maximum value set by the oscillator.[1] The form of the envelope of the sine wave is that of the continuous function

$$y = e^{kt} \qquad (1)$$

The attenuator operates electrically like a conventional voltage

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[1] In the block diagram, this unit is designated as a "log attenuator". The terms "exponential attenuator" would be more accurately descriptive.

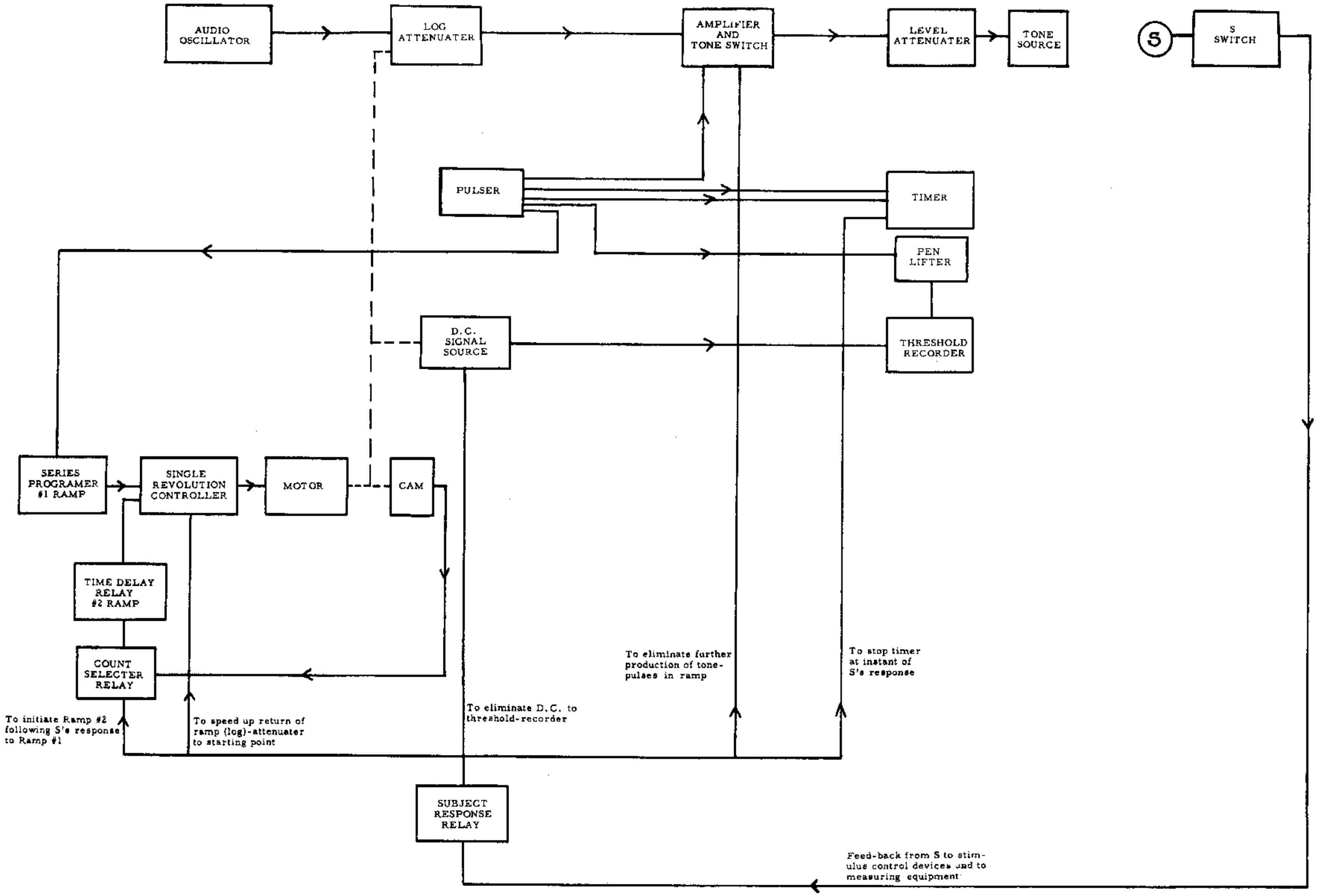

Figure 5. Block Diagram of Equipment Used for Measuring Absolute Thresholds and Reaction Times by the Double Ramp Method. (Lines Intersecting at Right Angles Are Not To Be Considered as Connected, Unless Point of Intersection Is Marked by Small Solid Circle. Dotted Lines Stand for Mechanical Linkage).

divider, with the leads from the oscillator connected across the terminals of the fixed resistor, to establish the maximum A.C. voltage, and the output leads, from one end of the resistor and from the wiper contact connected to the next stage of the cascaded series of units.

The only somewhat uncommon feature of the attenuator is the nature of the wiper contact, and the manner of moving it. The fixed resistance is a longitudinal tubular unit, 21 inches long with a total resistance of 500 ohms.

The wiper contact is provided by a silver wire wrapped around a cylindrical drum of the same length as the resistor. The drum, 6 3/4" in diameter, is placed alongside of the resistance unit, and parallel to it, so that the silver wire touches the resistance only at one point. As the drum is made to rotate from the starting position, this point of contact moves from one end of the resistance, the reference or zero potential end to the far end, and, at a rate equal to the derivative of the function in Eq. (1), even though the drum is rotating at a constant rate. This result is accomplished by first plotting the exponential function on graph paper cut so as to equal in area and proportions the cylindrical surface of the drum. The pure silver wire is then carefully cemented to coincide with the plotted curve, and the paper with its silver line wrapped snugly around the drum. The silver wire is extended to the flat end of the drum to provide a continuous conducting path to the external terminals through the drum bearing.[1]

The reason for our wishing to modulate the sine wave exponentially will probably be apparent. Our objective was to provide a continuous tone or a sequence of tone pulses which would increase linearly in loudness. Since the perceived intensity of the sensed or perceived tone approximates the logarithm of the physical intensity, it was necessary that the physical intensity increase exponentially in order for its logarithm to increase linearly.

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[1] A considerable amount of exploratory work was necessary before we were able to develop suitable procedures for mounting the wire on the drum in a way to provide continuous contact and accurate functions. This work was carried out by Mrs. Ernestine H. Kreezer.

Thus the logarithm of e^{kt} to the base e is kt, a linear function with a slope equal to k.

Another way of stating this same requirement is to say that we wished the intensity of the stimulus to increase linearly when measured in decibels, since the intensity of the stimulus in decibels is proportional to the log of the physical intensity, relative to some reference value.

To check on the accuracy of the exponential potentiometer, the output voltage was measured in db. on a Ballantine electronic voltmeter as a function of the angular displacement of the drum from its starting position. A linear function, with intensity measured in decibels, would be evidence of the accuracy with which we were simulating an exponential function. A good linear fit was obtained except for very small angles, corresponding to the weakest intensities. The obtained curve will be presented later in relation to a description of our method for automatically recording threshold values.

(3) Tone Switch. This unit, used in conjunction with a pulsing unit made it possible for us to break up the exponentially modulated sine wave into pulses. The controlling pulses, rectangular pulses of constant magnitude, were produced by a Grass Stimulator Model 400, designated as a Pulser in the block diagram. It was set to produce pulses 0.1 sec. in duration, at intervals of 1.2 sec. A train of such pulses, fed into one channel of the tone switch resulted in an output of sinusoidal waves, the envelope of which showed the time pattern imposed by the Pulser but an amplitude determined by the exponential attenuator. That is to say, the output of the tone switch was a sequence of pulses with a sinusoidal carrier, the frequency of which was determined by the audio-oscillator, and of exponentially rising amplitude.

The tone switch introduced one additional feature into the shaping of the tone pulses. It permitted the rectangular corners of the pulses to be rounded to an extent sufficient to prevent clicks from being heard in the telephone receiver or loud speaker when the electrical signals were received by these tone sources. This adjustment of rate of rise of the pulses was made by the investigator by ear, at the start of a given auditory investigation and then left constant for the entire investigation. Such elimination of any clicks was considered necessary in order for us to be sure that obtained thresholds corresponded to the stimulus-frequency established by the investigator. If the subject responded to a click instead of to a pure tone free from clicks, it would mean that he was probably responding to frequencies different from those assumed by the experimenter. For a click implies the presence of a wide variety of frequencies. Possibly another way of saying this is that the Fourier analysis of a rectangular tone pulse includes many frequencies in addition to that of the carrier wave. It was necessary that such transient frequencies be reduced beneath the carrier frequency in audibility.

A second additional function of the tone switch[1] was the provision of additional amplification when needed. Such amplification was required in the experiment carried out with high level of background noise relative to that required in the study with zero background noise.

(4) <u>Level Attenuator.</u> The next unit is a commercial Hewlett Packard Model 35A attenuator, calibrated in decibels. It made it possible for the ramp as a whole to be set at a level near threshold for the particular frequency being presented to a subject in the next pair of ramps. This adjustment was made by the experimenter at the same time that he set the oscillator frequency, subsequent to the presentation of a given pair of ramps, in preparation for presentation of the next pair.

(5) <u>Sound Sources.</u> Two types of sound source were used for presentation of the tone-stimuli to the subjects: (a) a pair of Permaflux 6-inch speakers for the study involving zero background noise, and (b) a Permaflux Type PDR10 telephone receiver, specified as having an approximately flat characteristic, for the study involving high level background noise.

Frequency response curves showing sound output as a function of frequency were established for both of these sound

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[1] The unit used as a tone switch was the electronic Dual Switch manufactured by the Wichita Apparatus Company.

sources[1] in order to permit us to correct absolute threshold determinations for deviations from a flat characteristic in the sound source. Such correction is not required in the presentation of data involving task-set threshold differences, since the taking of such differences automatically corrects for frequency differences in measured threshold due to absence of a flat characteristic either in the sound source or the sensory receptor.

This completes the description of units in the first row of the diagram which are involved in the important function of determining the properties of the stimulus-tones presented to the subject. The first four units operate in the domain of electrical signals. Only in the last stage is the electrical pattern previously fashioned converted into sound. Of the four purely electrical stages, the first generates a carrier wave of specific frequency; the second shapes the envelope of these waves; the third breaks up the continuous envelope into pulses; and the fourth establishes the absolute intensity level. The final stage may be considered a transducer which preserves the form of the signal, but changes the physical dimensions of the carrier, from electrical potential to mechanical pressure, a dimension to which the auditory receptor of the subject is capable of responding.

B. Recording of Threshold Values

The equipment principally involved in the automatic recording of the threshold values is shown in the third row of the diagram.

The D.C. Signal Source consists of a constant 6-volt D.C. supply connected across a 10-ohm pot capable of continuous rotation, without mechanical stops. As indicated in the diagram, the motor is coupled mechanically, by means of a chain drive to this pot and the drum of the exponential potentiometer.

The two units will move synchronously, and hence there will be a one-to-one correspondence between the voltage output of the attenuator and of the pot. Since the output of the pot can be con-

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[1] We should like to thank Dr. Jerome Cox and his colleagues in the acoustic laboratory of the Central Institute for the Deaf of St. Louis for obtaining these frequency response curves.

sidered a linear function of time, equal to k_2t, and the output of the attenuator a rising exponential function of time with an exponent k_1t, the function generated by the pot can be regarded, except for a proportionality factor, as the logarithm of the function generated by the attenuator. Hence, after proper adjustment of the value of the constant k_2, the combination of the attenuator and pot can be regarded as a logarithmic computer, with an input equal to the output voltage of the attenuator, and the output of the computer equal to this voltage in decibels. Since the intensity of the sound wave pulse presented to the subject as a stimulus at a given instant will be proportional to the voltage output of the exponential attenuator, the output of the pot may also be regarded as indicating the intensity of the sound wave stimulus in decibels, after proper adjustment of the proportionality constant.

In brief, a record of the voltage output of the D.C. pot as a function of time provides us with a record of the intensity in decibels of the stimuli presented to the subjects. The strip chart recorder to which the D.C. signal source is connected gives us that record. It is designated in the diagram as a threshold recorder. The record consists of a straight line which rises with a slope that represents the increase in intensity of the stimulus in db. per sec.

Whenever the motor driving the combination of drum (in the exponential attenuator) and the D.C. pot is energized, the subject is presented with an ascending series of tone pulses, and we obtain a simultaneous record, on the strip chart recorder, of the magnitude of the stimulus at any instant. In order to indicate on the record the specific time at which pulses of sound are actually being presented to the subject, a solenoid is provided to lift the pen from the paper every time the tone-pulses occur. The resulting gaps in the record represent the stimulus pulses. A synchronism between the stimulus-pulses and the actuation of the pen lifter occurs since the Pulser, which determines the instant at which the tone pulse occurs, also is connected to the pen lifter, as shown in the diagram.

To indicate the particular pulse to which the subject responds, that is to say, his threshold pulse, we need only provide a way for this particular pulse to be indicated on the chart when the subject perceives the stimulus. To accomplish this result, the subject is provided with a key and asked to press it as soon as he perceives the tone signal. This key is connected to the coil of a relay, the subject-response relay shown at the bottom of the diagram. One of the pairs of contacts in the secondary of this relay is connected across the input terminals of the strip chart recorder. Hence when the subject presses his key to indicate his perception of the stimulus, the input to the recorder is short-circuited and the recorder-pen returns to its zero position. The subject-relay is a latch-type relay which remains closed until the drum has returned to its zero position and the D.C. output of the pot has therefore returned to zero.

The record thus consists of a ramp traced on the strip chart, with gaps in the line to show when tone-pulses were presented. The gap nearest the peak of the ramp indicates the value of the threshold stimulus. Since in this study we are interested in the differences between the task and set thresholds, and not absolute levels, we need merely determine the difference between the levels of the final gaps in the pair of ramps traced on the record. This difference is recorded in "Brown units", which refers to the units as marked off on the chart paper itself. Across the entire width of the 11-inch chart paper there are 100 Brown units.

The task-set threshold difference, associated with any pair of ramps, in Brown units, can be easily determined by inspection. Multiplication of this value by a constant, representing decibels per Brown unit, gives us our final measure in decibels. For the auditory studies this conversion constant was 0.4 decibels per Brown unit.

C. Measurement of Reaction-Times

The second row of the diagram shows the units involved in the measurement of reaction times. The strip chart record described above actually provides a basis for determination of reaction times, though not with sufficient precision. The distance between the beginning of the gap nearest the peak of the recorded ramp and the peak of that ramp corresponds to the time interval which elapses following the start of a 0.1 sec. tone pulse. Thus our strip chart record, since it is a complete record of the ascending series of stimuli, up to the moment of subject response, provides the material for both threshold determinations and reaction time measures. The intensity scale of this record is such as to give us a sufficiently precise measure of threshold values; the time scale, however, is condensed and requires the use of supplementary procedures to provide adequate precision. These supplementary procedures can be regarded as merely a means of stretching out the time scale of our strip chart record.

This point of view suggests a means for obtaining a record of reaction time. We need a clock, with sufficiently small units, such as millisec., which will start running at the inception of the stimulus-pulse to which the subject responds, and stop as soon as he presses his response key. The elapsed interval will measure the subject's reaction time with the beginning of the stimulus-pulse as a zero-reference. If we wish to take the end of the pulse as our reference, we need only subtract 0.1 sec. from the elapsed interval.

Now there is obviously no technical difficulty in obtaining a clock which will stop when the subject presses his key. A little planning is required, however, to get the clock to start with the particular pulse to which the subject responds. This difficulty does not arise in the conventional experiment for measuring reaction times. In the usual determination, a single stimulus only is presented in a single determination of reaction time. The event which releases the stimulus can also be made to start the clock, the pressing of the subject's key to stop the clock, and the reaction time will be indicated on the dial of the clock or its equivalent display screen.

In the present situation, however, it is not possible to know ahead of time to which specific pulse in the sequence of pulses of increasing intensity the subject is going to respond. Hence it becomes necessary to start the clock, or its equivalent, at the instant of presentation of <u>each</u> succeeding pulse, to allow the clock to run for approximately the entire interval up to the next pulse, and then to reset the clock to zero at the inception of the next pulse, in case the subject has not responded. Then, when the subject finally responds to a particular pulse, his closing of the key must not only stop the clock, but must also eliminate any succeeding pulses so they will not impinge on the clock and restart it before the experimenter can take a reading.

To meet these conditions we searched for a clock that could be reset by each succeeding pulse in a sequence of pulses. An electronic type of timer, based on electronic counting of an internally generated high frequency oscillation, was selected as a suitable instrument. The instrument used, a Hewlett-Packard Model 522 B electronic timer, did not permit each succeeding pulse to stop the timer, reset it to zero, and restart the timer, all in the same instant, but it made possible an equivalent result when used in conjunction with our Pulser. The Grass Type stimulator, designed primarily for generating rectangularly shaped electrical pulses for use in stimulating nerves in physiological experiments, was used as our Pulser. It provides, in addition to the sequence of rectangular pulses for which the dials are set, a synchronizing pulse of very brief duration, and from a separate terminal, which was intended to be used for initiating a single sweep on cathode ray oscilloscopes, prior to the stimulation of the nerve and the recording of the electronic or action-potentials.

In our application, the synchronizing pulse was made to come .07 sec. before the start of the next pulse. The lead from the synchronizing terminal of the Pulser was connected to the stop channel of the electronic timer. Consequently, if the subject had not responded to a pulse up to .07 of a second before the next pulse, the timer was stopped. (The value of .07 sec. was used since this was found to be about the shortest interval that would result consistently in stopping the electronic timer in time for the next positive pulse, applied to the start channel, to start it.) The advent of a new electrical pulse now, connected to the start channel of the electronic timer, will automatically reset the timer to zero and restart it. This dual event will occur, however, only if the timer has first been stopped. Hence the usefulness of the synchronizing pulse from the Pulser.

The diagram shows the two lines extending from the Pulser to the timer. The top line stands for the pair of leads from the rectangular pulse output terminal of the Pulser to the start channel of the timer; the lower line for the leads from the synchronizing pulse terminal to the stop channel of the timer. A second connection to the stop channel comes from the subject-response relay. In the diagram this connection is shown as a third line into the timer. Actually, in series with a D.C. supply, it is connected to the same stop channel as is the lead from the synchronizing terminal of the Pulser. Hence, either the synchronizing pulse or the pulse initiated by the subject-relay can stop the timer.

Once the timer has been stopped, the count recorded on the neon-type dials remains visible until the attenuator-drum has completed a full revolution and comes to a stop. At the same time, one of the cams associated with a single revolution controller, to be mentioned below, causes the starting-lead from Pulser to Timer, which has been opened by the closing of the subject relay, to be closed; the timer then starts again to measure the time interval between successive pulses, even though the drum is not turning.

With the present set-up, it was necessary for the count registered on the timer to be read off by the experimenter following each response of the subject. The interval between pulses was made long enough (1.2 sec.), so that there was plenty of time for this reading to be taken even after the lapse of time required for the pre-threshold portion of the ramp. Another reason for this interval between pulses being made as long as 1.2 sec. was to provide plenty of time for the reaction time to be completed, even abnormally long reaction times, before the occurrence of the time for the next pulse.

D. Control of the Temporal Programming of Ramps

The time interval between pulses within any one ramp is controlled by the Pulser, as indicated in the diagram by the line drawn from the Pulser leads to the Tone Switch. We have not yet considered how the interval between the first members of each pair of ramps and the interval between the first and second ramps in a pair is controlled. The apparatus grouped together in the lower left-hand region of the block diagram shows the principal pieces which are involved in these operations. Let us start with the Series Programmer and trace the sequence of events initiated by it.

(1) Series Programmer. This unit is a Gerbrands Program Timer. It operates by feeding a strip of 35 mm. motion picture film, in which holes are punched at appropriate intervals, past a metal finger which determines the closing and opening of an adjacent micro-switch (Sw. #1). Whenever a hole reaches the metal finger, the switch is closed, to stay closed until the metal finger no longer protrudes through the hole. A synchronous motor for feeding the film or tape assures a constant speed of progression. The holes can be cut into the tape accurately, by means of a special punch, and spaced

to provide the time intervals specified in the design of the experiment. The time intervals are varied in random order to prevent anticipation of any given test signal in ramp #1 by a subject (See Kreezer, 1958).

(2) Single Revolution Controller and Motor. The core of the "Single Revolution Controller" is a General Radio Type 1701 AK Variac Speed Controller. This is a device to permit the speed of a D.C. motor to be varied by control of a Variac in the controller unit. The principles involved in the conventional operation of these units is explained in the literature of the manufacturer.

The controller unit, containing a Variac and rectifiers supplies power for the D.C. motor. In our application, a unit containing several switches and a cam is inserted between the D.C. motor and the Variac controller, so that closing of one of these switches is required to start the motor, and the opening of particular switches by a disc-like cam mounted on the shaft of the motor will cause it to stop.

Let us assume that two switches in parallel are inserted in one power lead between Variac controller and motor. Sw. #1 is the switch operated by holes in tape of the programmer. Sw. #2 is operated by a disc with a notch cut in it that is mounted on the shaft of the motor. One of these switches must be closed to keep the motor running. At the end of a single revolution of the motor, the notch in the disc permits Sw. #2 to open, but the disc keeps it closed at any other time. Sw. #1 is closed only when a hole appears under the metal finger of the programmer.

The net effect is as follows. The closing of Sw. #1 by the hole in the tape starts the motor. This causes movement of the notch through a small angle and allows Sw. #2 to close. The motor therefore keeps running even after the hole in the tape has moved beyond the metal finger. At the end of a single revolution, the notch in the disc causes Sw. #2 to open, and the motor stops. The effect has been to bring about one cycle operation of the motor. The single revolution will be repeated whenever a hole appears in the tape to again close Sw. #1 for a brief interval. This initial revolution provides for Ramp #1 our ascending series of stimuli.

The second ramp is brought about through a third switch (or pair of contacts), Sw. #1B, being placed in parallel with Sw. #1, so that its momentary closing can substitute for Sw. #1 in starting the motor. The holes in the tape are spaced about 1- 1/2 minutes apart, on the average, so that Sw. #1 will not close again for this interval following its initial action in starting the motor.

Its substitute, Sw. #1B, is located in the secondary of a time delay relay. The primary coil of this relay is controlled by the closing of a pair of contacts in the secondary of the subject response relay. Hence, when S presses his key to indicate he perceives a tone pulse in Ramp #1, the subject-relay closes, thereby energizing the delay relay to close Sw. #1B six seconds after the subject has responded. The second ramp is thus initiated by the subject's own response and Sw. #1B.

The response of the subject to a pulse in Ramp #2 would cause this action of the delay relay to be repeated if it were not for the insertion of a switch (Sw. #4) in the line between the coil of the delay relay and the secondary of the subject relay. This switch (Sw. #4) is in the secondary of what we have designated as a "count selecter relay". It is a ratchet type relay that is energized by a pulse in such a way that Sw. #4, if initially closed, will be opened at the first pulse to the relay coil, closed at the second pulse, opened at the third, and so on. A relay of this type.can in effect count, so as to discriminate between even and odd numbered pulses.

To provide the pulses necessary to operate our counter relay a metal finger is attached to the shaft of the motor. By actuating a microswitch (Sw. #5), it causes a pulse in the microswitch circuit near the end of each revolution of the motor. Sw. #5 is in the primary circuit of the count selecter relay. Hence every revolution of the motor causes Sw. #4 to change its status of being closed or open. As a result, the response of the subject to Ramp #1 finds Sw. #4 closed, so that the delay relay can initiate Ramp #2; but subject-response to Ramp #2 finds Sw. #4 open - and a new ramp cannot be initiated until Sw. #1, in the Series Programmer, again initiates Ramp #1 of the second pair of ramps.

The overall result is that a hole in the Programmer-tape is required to initiate the first ramp of any pair; but that Ramp #2 can be initiated by the subject's response by way of the delay relay. Consequently ramps will always occur in pairs and the time pattern of the intervals between pairs will be determined by the spatial pattern of holes in the programmer-tape.

E. Other Effects of Subject's Response

It is necessary now to call attention to a few additional effects that are produced when the response of the subject energizes the primary of the subject-relay. There are a number of additional pairs of contacts in the secondary of the subject-relay which are connected to units already mentioned in such a way as to produce a number of special effects. These effects are indicated in the diagram by the lines leading away from the subject-relay, and the associated captions.

The first effect is that of accelerating the motor driving the drum of the exponential attenuator. This is accomplished by connecting two wires to the Variac and to the Variac controller and short-circuiting them by a pair of relay contacts.

The motor and drum are thereby made to rotate more rapidly. The drum is no longer required to rotate at its standard pace since the subject has already responded to a pulse in the ramp. It is necessary now to get the drum back to its zero position before the 6 sec. delay interval is over. Hence the need for acceleration of the drum after the subject responds.

A second effect is the elimination of all tone stimuli at higher intensities in the ramp. This is accomplished by a connection to the amplifier and tone switch, which opens the line transmitting signals in the signal channel shown in the first row. A companion effect is the elimination of pulses from the Pulser to the Timer so that the dials of the Timer will not be cleared until the drum has returned to its original position. This result is also accomplished by the use of a relay, not shown in the diagram.

A third effect is the elimination of the D.C. signal from the D.C. Signal source to the Threshold Recorder. This effect is indicated by the line drawn from subject-relay to a D.C. signal source. It is easily accomplished by short-circuiting the output of the signal source. Such short-circuiting is desirable in conditions in which an open circuit in the input circuit to a measuring instrument would result in noise pick-up. The elimination of the signal to the threshold recorder causes the ramp being traced on the graph paper to return to zero, as mentioned earlier. We thus have a record of the threshold intensity.

A final effect, also necessary for measurement purposes and previously mentioned, is the provision of a stop-signal to the Timer, to indicate the instant at which the subject has responded. The numbers left in the display device of the instrument provide a measure of the reaction time, which is recorded manually by the subject.

We may summarize by listing the chief functions performed by various sections of this system. The channel in row #1 provides the tone-stimuli, though under the temporal control of outside units. The units in rows 2 and 3 provide for measurement of threshold and reaction time in the manner described. The group in the lower left-hand area is responsible for the time pattern in presentation of pairs of ramps, the initiation of the second ramp of a pair by the subject's response, and imposing of single cycle operations of the motor. Finally, the subject response relay initiates a whole set of events, mostly inhibitory in character, which influence the stimulus conditions for the subject and the securing of adequate measurements of threshold and reaction-time.

F. Stability of Equipment and Its Adaptability for Presentation of Visual Stimuli

The descriptions given of the apparatus involved in the measurement of the attention-value of warning signals has apparently related so far only to auditory stimuli. It may be regarded as holding, however, except for changes in the quality of the stimuli, for visual stimuli as well.

It will be noted that the top row of the block diagram is the part that is primarily concerned with determining the quality of the stimulus. If we substitute for each unit in the top row, the piece we used for discharging the same function, in the visual sphere, we will have a description of the apparatus-system used in investigating the attention value of visual warning signals.

The beauty of the present system lies in its adaptability, the possibility of utilizing it in the investigation of a wide variety of stimuli. It is really the culmination of a long period of trial and error, and was evolved in an effort to get an organization of pieces that would have maximum stability and reliability. The obvious choice, to us, in initially attempting to develop equipment for the functions with which we were concerned was electronic equipment. We had in fact a system completely electronic in character for accomplishing the same purposes as the present system. Experimental studies were started with this electronic equipment as a basis. We found, however, that reliable and accurate functioning of the equipment was so dependent on a wide assortment of conditions that whenever we were ready to obtain data from subjects, some component or other would be found defective or operating at the wrong value, and we despaired, without a much more elaborate staff to test and maintain the equipment, of ever getting dependable results. Repeated trials of alternative electronic circuits led to no substantial improvement. In these circumstances the only alternative seemed to be to reconsider the whole apparatus problem from the start, and to attempt to devise equipment that would be maximally stable and reliable, with a minimum of preliminary adjustment, testing, and calibration required each time the equipment was used.

In an effort to meet these needs, we turned to mechanical devices or relatively simple electrical circuits rather than electronic components. The manner of combination of units essentially stable in themselves became the means for achieving the desired results.

As a result of this change in point of view, the entire electronic system was discarded and the present one substituted for it. There are still a few accessory units, generally those dependent on electronic components, such as the blanking circuit, in which check and adjustment prior to an experimental session are required. But on the whole, the system operates in a consistent and reliable manner, as soon as it is turned on, and without a long period of preconditioning.

The channel substituted for the top row in the block diagram, in order to investigate visual stimuli, consisted of the following units: (1) a Beckmen monochrometer in place of the audio-oscillator, (2) a circular neutral wedge, with a range in density of 3, instead of the exponential attenuator, (3) a lightweight shutter, actuated by an electro-magnet, but driven by the same Pulser used previously, in place of the tone switch, and (4) a set of fixed neutral wedges, that could be selected automatically, in place of the Level Attenuator. The monochrometer was placed behind and to the side of the subject, with the circular neutral wedge, the wheel containing the fixed neutral wedges, and the lens-system for focusing the beam of light attached to, or mounted on a short optical bench in front of, the monochrometer. The operation of the entire system was then exactly equivalent to that described for the auditory system, with all the pieces below the top row in the diagram functioning in the same manner as before.

In the setting of the frequency (wave length) of the stimulus-source and of the intensity level prior to each ramp, some changes were required. With the audio set-up, the oscillator and attenuator were located in the experimenter's room, and could be adjusted without disturbing the subject, since these units were electrical in character and the signals were not converted to the final stimulus-dimension, sound, until the very last stage, the loud-speakers located in the subject's room. In the case of the visual set-up, the initial source, the monochrometer, had to be located in the subject's room. Hence some remote control of wave length and level was required, if we wished to avoid an extra experimenter stationed in the subject's room, to set wave length and level prior to each experimental trial. To meet this problem, selsyn control was substituted for direct manipulation of dials.

The wave length control knob on the monochrometer was removed, a platform was attached to the top of the monochrometer for holding a selsyn unit, and the shaft of a repeater-selsyn coupled to the wave-length shaft of the monochrometer. In similar fashion, a wheel containing slots for neutral filters of different density was placed in front of the monochrometer slit, and this wheel mounted on the shaft of the repeater unit of a second pair of selsyns.

The transmitter selsyns were located on the control-table in the experimenter's room. He was thus able to set the appropriate wave-length and fixed density level in the interval of time between every pair of ramps, in accordance with a predetermined schedule. When the subject subsequently made his pair of responses, the experimenter needed only to record the reaction time immediately following each ramp, and then, in addition, set in the wave length and level for the next trial following the second ramp of a pair. The threshold was automatically recorded on the strip chart recorder, and required no attention from the experimenter at all.

We have, for simplicity of exposition, spoken of the visual channel as substituted for the audio-channel shown in the top row of the diagram. As a matter of fact it was set up as a completely parallel channel to the visual, with a relay provided for switching all necessary control leads from units below the top row to either the set of audio units or the appropriate visual units when they cannot operate simultaneously in parallel. Thus, by merely actuating a toggle switch, the experimenter can at any instant select either a visual stimulus or an auditory stimulus for the next trial, and it is thus possible to conduct an investigation involving an intermixture of visual and auditory stimuli randomly distributed in the same experimental series. It will be quite feasible, in fact, to carry out this switching by means of a programmer, such as the tape used in programming the successive pairs of ramps, and thus automatically determine whether an auditory or visual stimulus is to be presented. This flexibility opens up the possibility of simulating quite complex sequences of stimuli, or warning signals, that move back and forth randomly from one modality to another, and thus investigating possible differences in efficiency.

G. Calibration Curves

Figures 6 and 7 are included to show the linearity of calibration curves for both visual and auditory stimuli. These are illustrative calibration curves which held with great consistency at different check-intervals. Both of these curves are relevant to the interpretation of the threshold records and data. They show the relation between the intensity of the threshold stimulus as recorded in "Brown units" and the equivalent specification in physical units. Thus in the case of auditory stimuli, the relation is between stimulus intensity in decibels and in Brown units, and in the case of the visual stimuli between intensity measurements in per cent transmission of the neutral wedge, or density, and Brown units. In both cases, for the portion of the curve involved in measuring the threshold differences between the peaks of the first (task-threshold) and second (set-threshold) ramps, the curves are linear and Brown units may easily be translated into physical units by multiplication by a constant.

The optical calibration curve was obtained through use of a Photovolt Model 500 Photoelectric Photometer. The audio-calibration curve was obtained by means of a Ballantine Model 300 electronic voltmeter to get measures in decibels at the output of the Level attenuator. The values in decibels given in Figure 6 are based on measurements at this point, with 1 millivolt taken as zero decibels.

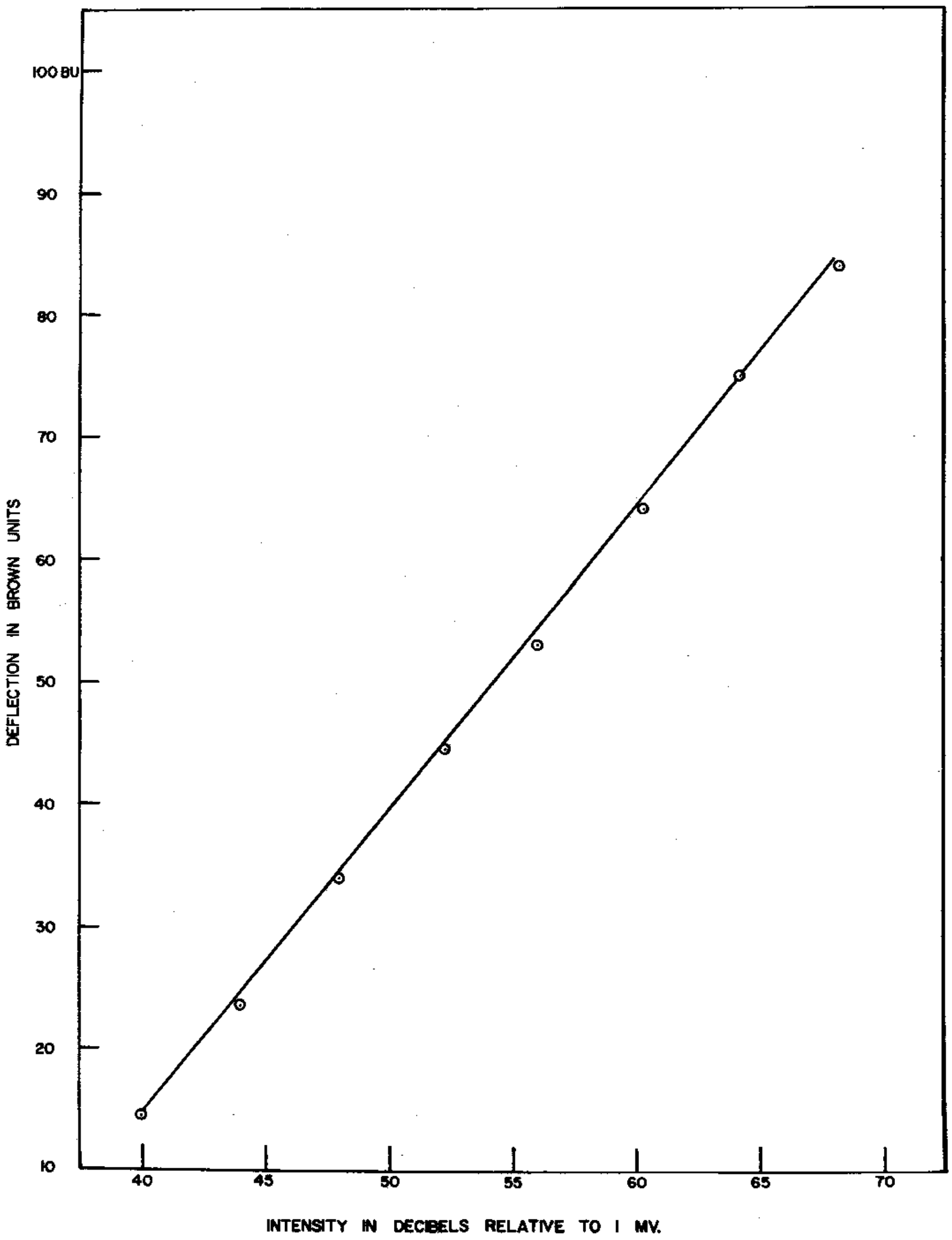

Figure 6. Calibration Curve Relating Intensity of Auditory Stimuli to Deflection on Threshold Recorder. (Intensity is Measured in Decibels at Output of Level Attenuator and Deflection in Chart Units Designated as "Brown Units".)

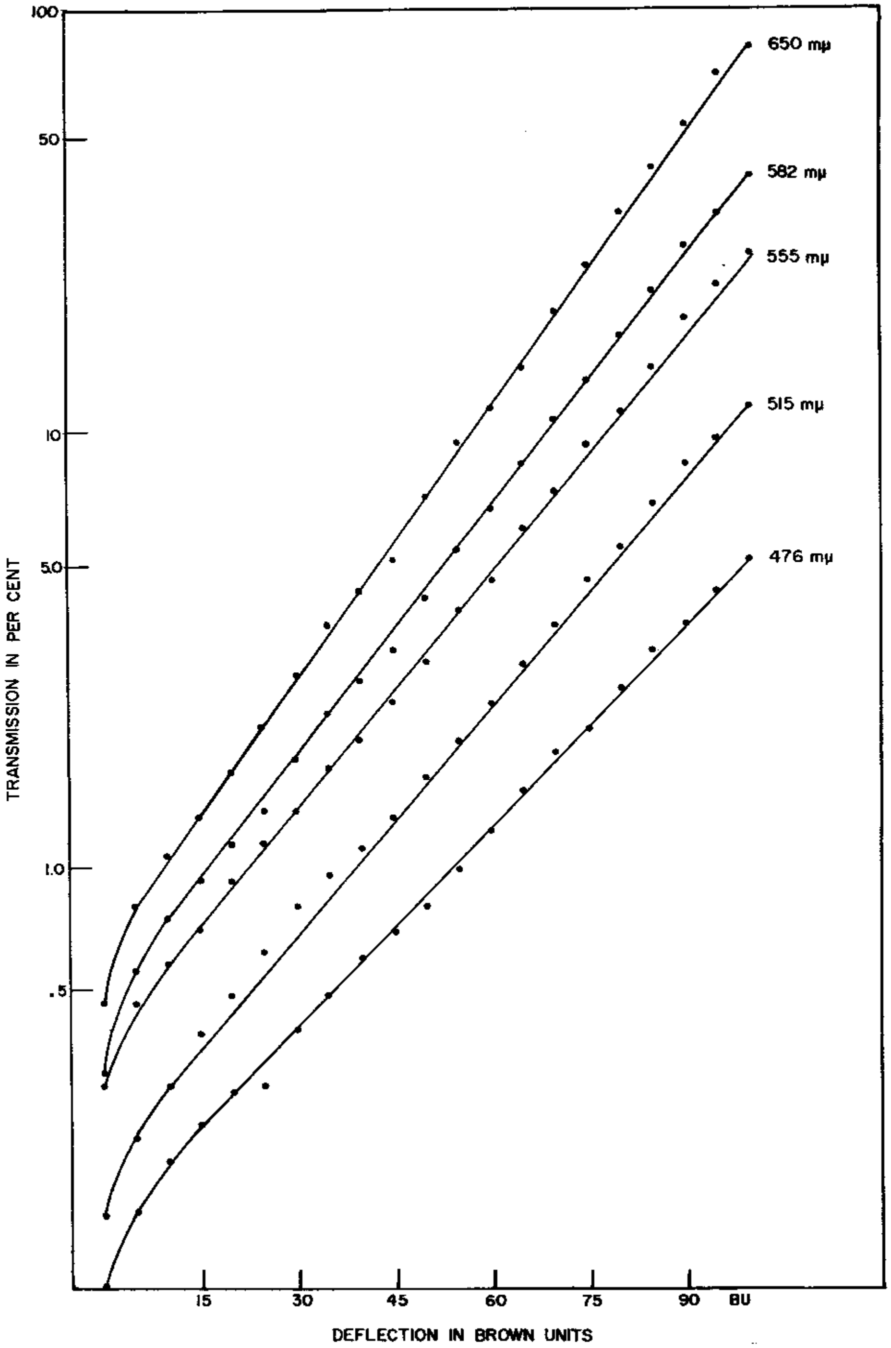

Figure 7. Calibration Curve Relating Intensity of Visual Stimuli to Deflection on Threshold Recorder. (Intensity is Measured in Units of Transmission Relative to an Arbitrary 100 Per Cent Point, and Deflection in Chart Units Designated as "Brown Units.")

To establish the fact that the linearity shown in the curve will also hold for the auditory stimuli themselves, determinations were made of the constancy of the transfer ratio between the electrical signals measured at the output of the Level attenuator, and the intensity of the sound stimuli measured by a calibrated Alter-Lansing condenser microphone located at the position of the subject's left ear.

APPENDIX III

SUPPLEMENT TO BIBLIOGRAPHY ON ATTENTION*

This Appendix is presented as a supplement to a previous report (WADC TR 54-455) intended to provide a bibliography and classification of the psychological literature on attention. The period covered is primarily from July 1954 to May 1957, the latest date for which the Psychological Abstracts was available. Some titles falling outside this period which have come to the authors' attention are also included.

As in the previous bibliography, the chief source of titles included was the Psychological Abstracts. In our scrutiny of titles, our search included terms related to attention, such as alertness, vigilance, and set, as well as those dealing specifically with attention. In the period covered by the present report, the concept of set yielded many more references than did the others included in our search. This shift suggests a change in the direction of interest of psychologists working in areas related to phenomena of attention.

The titles are given in alphabetical order. Due to the relatively small number of titles included in this report, we have not here given a classification of titles as was done in the previous report. The titles given may, however, be quite readily classified in relation to the rubrics given in our previous classification by the reader interested in a particular subtopic.

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*This supplemental bibliography was compiled jointly by G. L. Kreezer and M. K. Kleinhammer.

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