SIMULTANEOUS AUDITORY AND VISUAL DISCRIMINATIONS

INTERACTION BETWEEN AUDITORY AND VISUAL DISCRIMINATIONS ATTEMPTED SIMULTANEOUSLY

by

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SCOPE AND CONTENTS:

The study contains two discriminatory tasks which are attempted separately and simultaneously. The subject is asked to judge the relative positions of successively presented points of light and/or to decide whether a test tone is added to continuous white noise during the interval between the two lights. It is noted that this design is similar to a retroactive interference paradigm. Analysis of the data shows that there is little interaction between decisions to each of the psychophysical tasks when they are attempted simultaneously. There also appears to be no significant change in sensitivity whether the tasks are attempted alone or together. It is suggested that further experiments, involving different forms of visual memory, are needed.

Acknowledgment

I should like to express my sincere gratitude for the encouragement and guidance given to me by Dr. R. A. Kinchla throughout the development of this thesis. My thanks are also due to Dr. Lorraine Allan for her many helpful suggestions, and to Janice Burke who proved to be a most proficient typist. Finally, a word of thanks to three patient subjects, without whom these experiments would not have been possible.

Table of Contents

Figures

Tables

Introduction

The degree to which a person can perform two perceptual tasks simultaneously is a fundamental aspect of the concept of attention. If both tasks can be performed simultaneously with the same efficiency as they can be performed individually, there seems little need to introduce the concept of attention. However, if efficient performance of one task seems to be inversely related to efficient performance of the other task, some sort of attentive mechanism is suggested; i.e., it seems necessary to assume that a subject must "attend" to one task or the other, but that he may not "attend" to both simultaneously. In general, most experiments on attention have involved asking a subject to monitor ("attend to") more than one source of stimulation at the same time; e.g., he might be asked to listen to two voices simulteneously, or to read and listen simultaneously (Treisman, 1964; Kalsbeek and Sykes, 1966). However, few of the experiments on attention have involved simple psychophysical tasks in which perceptual factors such as set, past experience, and relative sensitivity to the stimuli in each task, can be adequately controlled and measured. The present research was designed to analyze a subject's ability to perform two very basic perceptual tasks simultaneously. The emphasis in the analysis is on a precise specification of the subject's sensitivity, unconfounded with other perceptual factors.

Kinchla (Kinchla and Smyzer, 1967) has distinguished detection from recognition on the basis of whether the two stimulus values to be discriminated occur in immediate temporal succession or not. In a detection task, the subject is asked to discriminate between two conditions which occur in immediate temporal succession. In a recognition task, he is asked to discriminate between two values (standard and comparison stimuli) which are not observed in immediate temporal succession. Recognition requires that the initially observed value be in some sense memorized until the second or comparison value is observed. Thus, recognition differs from detection in the degree to which memory processes are involved; detection is simply the special case in which memory plays a minimal role.

With reference to this distinction between detection and recognition, studies of attention to two tasks simultaneously can be of three types: both are detection tasks (Creelman, 1960), both are recognition tasks (Lindsay, et. al., 1968), or, one is a detection task and the other a recognition task. The present experiment is primarily concerned with the latter problem; specifically, it involves the detection of a tone superimposed on noise, and the recognition of a change in position of a light viewed in the dark. Each experimental trial consisted of two light presentations separated by a fixed length of time, followed by a response interval. Noise was presented to the subject through the earphones at all times, but the test tone could only occur during the interval between the two lights. The subject was asked to respond in one of three ways: to decide only whether the second light was in the same position as the first or displaced to the right (the recognition task); to decide only whether a tone was added to the noise or not (the detection task); or to make both decisions (the simultaneous detection/recognition task).

It should be noted that the experimental paradigm is similar to that used in studies of retroactive interference. The traditional form of such experiments involves the learning and retest of lists of word-pairs ("paired associates") and the assessment of the effect of interpolated activity. Recently, the effect of interpolated activity on kinesthetic memory has been investigated by Posner (1968), where it was found that forgetting of a movement is not affected by the interpolated tasks. However, in the same study it was also found that if the memorized material is verbal, then the same interpolated tasks greatly increase forgetting. It would seem, therefore, that the effect of interpolated activity is dependent upon the type of information that is memorized, and that no specific predictions can be made of the effect of an auditory task on visual position memory. However, Signal Detection Theory (to be discussed later) suggests that a consistent relationship exists between sensitivity and observation time; thus it should be possible to estimate the approximate length of time the subject was attending to the interpolated auditory task. Suppose the subject "attends" to the auditory problem during the entire interlight interval when he is asked to perform only the auditory detection task. A drop in auditory sensitivity when the subject is asked to perform both tasks simultaneously might be interpreted as a reduction in the time spent "attending" to the auditory stimulus during the interlight interval.

It is possible to distinguish two general types of memory processes: passive and active. A passive process would be one which was completely dependent on time and independent of the activity of the subject during the retention period. An active process is one which is not simply time dependent; for example, the type of "rehearsal" (covert verbal practice) memory process suggested by research on verbal memory where interpolated tasks seriously interfere with the retention of verbal material (Atkinson and Shiffrin, 1967).

In the present experiment when both tasks are attempted simultaneously, interference between visual and auditory performance would suggest that position memory is an active process, whereas no reduction in visual or auditory accuracy would suggest a passive memory process.

The Discrimination Tasks

In this section, the auditory and visual discrimination tasks will be defined in more detail and some notation introduced.

Each subject was seated in a dark room facing a visual display on which points of light were briefly presented. The first light of a trial always occurred in the same position on the display but the second, presented after a fixed time, could either be in the same position as the first or displaced horizontally to the right by a constant distance. Thus, this recognition problem, in some sense, required "memorization" of the position of the first light and the comparison of this "memory" with the perceived position of the second light. A difference in the positions of the two successive lights will be termed a "signal". Thus, there are two types of trials: signal and no-signal trials, which are denoted S_{i1} and S_{i0} respectively. The trials are represented in Figure 1, where the ordinate represents horizontal position and the abscissa represents time. The first light is represented as being at position X_0 having a duration of 1 second with its offset occurring at time zero. After t seconds, a second light is presented for 100 msec. at position X_t. The value of X_0 was zero on all trials while X_t could equal 0 or m.

Signal trials in the auditory problem, denoted by S_{1j}, are trials on which a 900 Hz. tone is added to the white noise for the entire t second interval between the lights. No-signal trials, denoted by S_{0j},

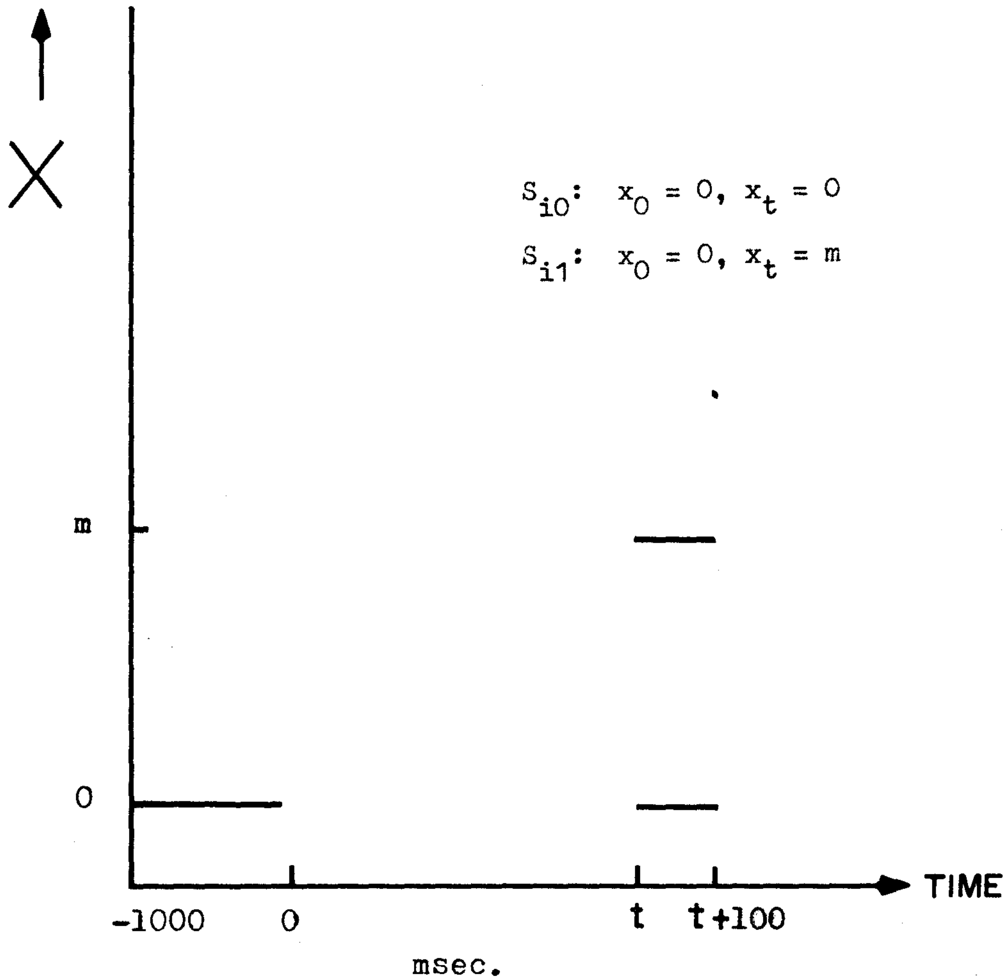

Fig. 1. Representation of signal (S_{i1}) and no signal (S_{i0}) trials in the visual problem.

are trials on which no tone is added to the noise. Figure 2 is a diagram of the two types of trials within the auditory problem.

When the visual and auditory problems are combined into one task, there are four different types of trials that may occur: signals in both sensory modes (S_{11}); a visual signal and no auditory signal (S_{01}); an auditory signal and no visual signal (S_{10}); or no signal in either sensory mode (S_{00}).

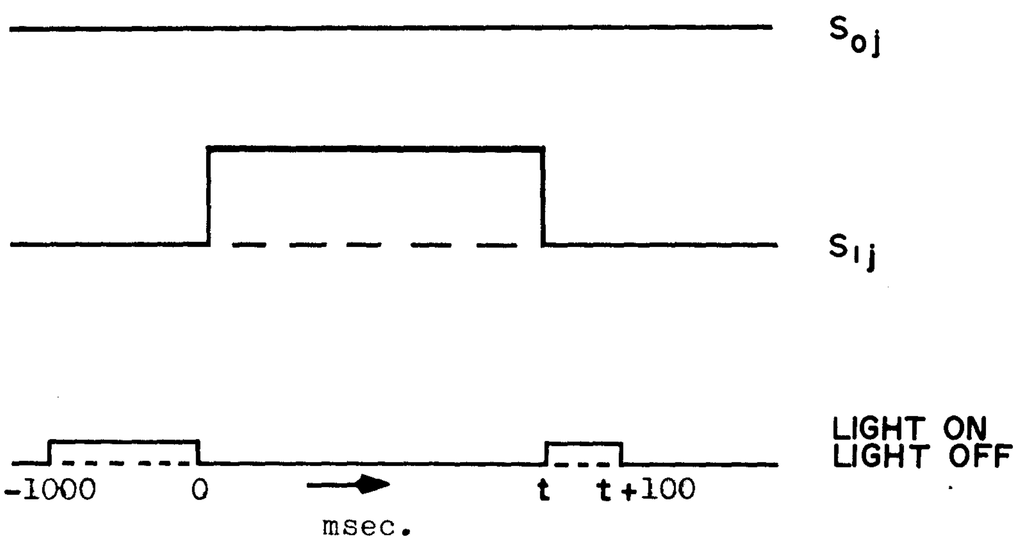

Fig. 2. Representation of signal (S_{1j}) and no signal (S_{0j}) trials in the auditory problem.

Discrimination Theory

Signal Detection Theory (Green and Swets, 1966) assumes that repeated inputs of the same stimulus do not necessarily evoke the same sensory value. The stimulus is represented as generating a hypothetical Gaussian distribution with an expected value equal to the actual stimulus value. Different stimuli may sometimes generate distributions which differ only in their mean values. In this study, the Gaussian distributions of sensory values, arising from the stimulus S_1 (signal plus noise) and the stimulus S_0 (noise alone), are assumed to have equal variance; S_1 evoking the distribution with the higher mean value. The distance between the two means, measured in standard deviation units, is denoted by d' and is dependent upon the physical values of the two stimuli and the subject's sensitivity.

Specifically,

$$d' = \frac{\mu_1 - \mu_0}{\sigma} \qquad (1)$$

where μ_1 and μ_0 are the means of the two distributions arising from S_1 and S_0 respectively; and σ is the standard deviation of the distributions.

The theory assumes that the subject chooses a cut-off point (the criterion value) above which he decides the input came from one stimulus pattern, S_1 (signal and noise). If the input falls below the cut-off point, then the subject decides that it came from the other stimulus pattern, S_0 (noise alone).

The detection process is thus the summation of two independent stages; the generation of a sensory value and its comparison to a cut-off point.

The value of d' may be calculated using the probability of hits and false alarms, denoted by P(H) and P(FA) respectively. The probability of a hit is that area under the S_1 distribution which is to the right of the cut-off point; similarly, the probability of a false alarm is the area under the S_0 distribution to the right of the criterion. Specifically, since the variances of the two distributions are assumed to be equal, d' is given by the following expression:

$$d' = Z(FA) - Z(H) \qquad (2a)$$

where Z(H) is that value of a normal deviate which is exceeded with a probability P(H), and Z(FA) is a similar transformation of P(FA). The important feature of d' is that it is a measure of sensitivity which is independent of the subject's choice of decision criterion.

In the auditory problem described previously, the S_1 stimulus is that arising from the tone plus the white noise and the S_0 stimulus is the white noise alone; if detection is imperfect, the distributions of sensory values evoked by these stimuli are assumed to overlap. The subject's performance may be summarized by the observed proportions of hits and false alarms: the proportion of hits is the number of times the subject correctly reports a signal divided by the total number of occurrences of the signal; the proportion of false alarms is the number of times a signal is incorrectly reported divided by the total number of no-signal trials. These observed proportions are treated as estimates of the corresponding theoretical probabilities, Z(H) and Z(FA); accordingly, these estimates will be denoted as $\hat{Z}(H)$ and $\hat{Z}(FA)$. Thus, these estimates can be used to obtain an estimate of d' by appropriate substitution in Eq. 2a;

$$\text{i.e., } \hat{d}' = \hat{Z}(FA) - \hat{Z}(H) \tag{2b}$$

where $\hat{d}'$ is an estimate of the theoretical d'.

A model for the visual position discrimination task has been proposed by Kinchla (Kinchla and Smyzer, 1967) which represents a subject's memory for the lateral position of the original point of light as a Gaussian random variable, M. The expected value of M is assumed to equal the original position of the light, X_0, while the variance of M is directly proportional to time, t; specifically,

$$E(M) = X_0 \tag{3}$$

and

$$Var(M) = \phi t \tag{4}$$

The observer is represented as reporting movement to the right only if the difference between M and X_t is greater than some response criterion, β.

It can be shown that this model yields a d' measure of sensitivity defined as follows:

$$d' = \frac{m}{(\phi t)^{1/2}} \tag{5}$$

where t is the inter-light interval in the visual recognition task, and m is the displacement of the light on S_{11} trials. As in the case of the auditory task, an estimate of d' can be obtained from the observed proportions of hits and false-alarm using Eq. 2b.

Note that the visual model predicts a change in the value d' when the time, t, between the two lights is manipulated. Specifically,

$$d'_2 = d'_1(t_1/t_2)^{1/2} \qquad (6)$$

where d'_2 is the sensitivity for an interlight interval of t_2 seconds and d'_1 is the sensitivity for an interval of t_1 seconds, and t_2 is greater than t_1. The manner in which the auditory d' is influenced by the duration of the observation interval can also be derived from Signal Detection Theory (Green and Swets, 1966). Specifically,

$$d'_2 = d'_1(t_2/t_1)^{1/2} \qquad (7)$$

where d'_2 is the sensitivity for an observation interval of t_2 seconds and d'_1 is the sensitivity when the interval of t_1 seconds; t_2 is greater than t_1. In the present experiment, interlight interval and auditory observation time must change together. Therefore, when t is increased, the visual d' should theoretically decrease while the auditory d' should increase.

Experiment One

The first experiment to be considered here was designed to evaluate whether efficient performance on the auditory problem was reciprocally related to efficient performance on the visual problem when both problems were performed simultaneously. The general strategy was to induce the subject to pay more or less "attention" to each of the two problems by giving him appropriate written instructions.

The subject was given one of five sets of instructions[1] before each 400 trial session. The instructions described different tasks ranging from one in which the subject only responded to the visual problem, Task 1, to one in which he only responded to the auditory problem, Task 5. Tasks 2 and 4 required responses to both problems simultaneously, but one problem was emphasized as being more important. Task 2 emphasized the visual problem while Task 4 emphasized the auditory problem. Task 3 was an intermediate or neutral instruction which asked for equal attention to both problems. It was hoped that this procedure would reveal any form of reciprocal relation that might exist between the sensitivity of the subject to the visual and to the auditory problem. A hypothetical trading relation of this sort is

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[1] The instructions given to the subjects are presented in Appendix A.

illustrated in Figure 3. The d' values calculated from Tasks 1 and 5 are assumed to represent maximum efficiency on a particular problem since that problem is attempted alone. Task 2, asking for simultaneous decisions on both modes but concentration on the visual problem, should produce a greater decrease in the auditory than the visual d' value; alternatively, on Task 4, a greater decrease in the visual d' value is expected. While on Task 3, which asks for equal attention to both problems, the visual and auditory d' values should be at some intermediate point between their respective maximum and minimum values. The open point in Figure 3 indicates the performance on Tasks 2, 3, and 4 which would be produced if there were no interaction between performance on the two problems when they are attempted simultaneously.

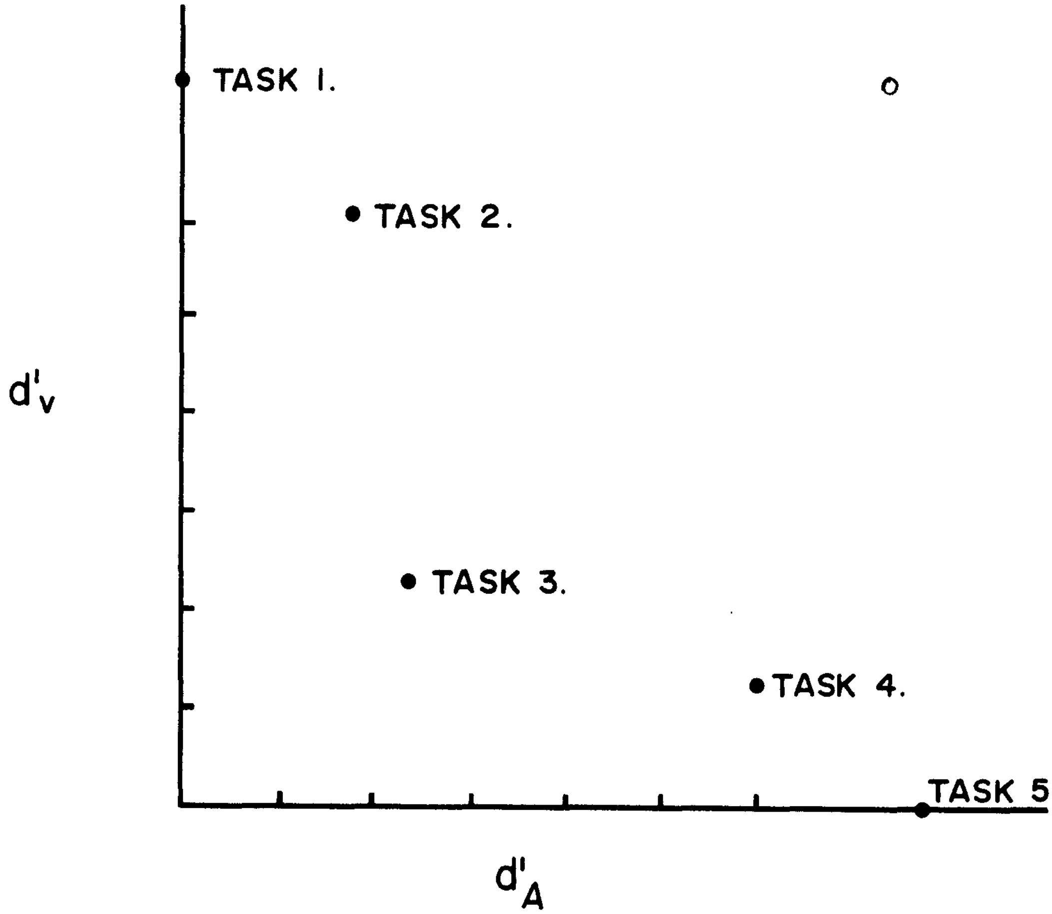

Fig. 3. Hypothetical Trading Relation between the Visual and Auditory d' values. (The open point indicates the performance one would obtain in tasks 2, 3, and 4 if the visual and auditory performances were independent.)

Apparatus and Procedure

The visual stimulus display was located 4.12 meters in front of the subject and consisted of two circular white lights in the same horizontal plane. Each light (Dialco No. 39, 28v, .04 amp., operated at 15v.) was 0.033 degree visual angle in diameter with a brightness of 43.0 millilamberts, with .4 degree visual angle separation between the midpoints of the lights.

White noise was fed through the earphones at all times. On some trials, a tone envelope was added to the noise during the inter-light interval. The tone intensity was such that the signal to noise ratio (E/No) was approximately 20. The subject sat in a conventional chair in the dark with no special constraints on his head position.

Two subjects were employed who had 20/20 vision or better as measured by a conventional Snellen test. They were non-psychology graduate students who were paid two dollars per session. Subjects performed for 20 daily, 400-trial sessions (lasting approximately 45 minutes each) including five preliminary practice sessions.

Each test trial was defined as follows. The first light flash was presented for 1000 msec. to provide the observer with adequate warning that the trial had begun. At the offset of this light, one of two events occurred with equal probability: a 100 msec. (including a 10 msec. rise and decay) 900 Hz. tone envelope was added to a constant background of noise; or no tone was presented. In either case, 100 msec. subsequent to the offset of the initial light a second light flash occurred lasting 100 msec. On a randomly-selected one-half of the trials, this second flash was in the same position as the first flash, while on the other half of the trials, it was displaced by a constant distance of 0.4 degrees visual angle to the right. After the second brief flash, the subjects were allowed three seconds in which to respond before the beginning of the next trial.

On all trials, the probabilities of the light changing position and the tone being added to the noise were each 0.5 and independent; therefore, S_{11}, S_{01}, S_{10}, and S_{00} each had a probability of 0.25 of occurrence on any one trial. The randomization was done in blocks of 100 trials with exactly 25 presentations of each stimulus pattern within each block.

It should be emphasized that whether or not the subject had to work on both the auditory and visual problems or on just one of them, the stimulus presentation schedule was the same; i.e., all four patterns were presented with equal probability.

All of the timing, stimulus production, and data recording were done automatically under the control of a P.D.P.8S computer.

The order of the five tasks was randomized within five day periods so that each task occurred once in each successive period. At the beginning of each session, the subject was given the set of instructions pertaining to the task for that day. He then had 48 practice trials (12 of each of the four stimuli) to enable him to become dark adapted and to become familiarized with the task for that session.

Four blocks of 100 trials were then presented, there being a rest interval of one minute between each block. The subject responded by pressing one of the four buttons fixed to the arm of the chair in which he sat. These buttons corresponded to the different responses (i.e., one button for each of R_{11}, R_{01}, R_{10}, and R_{00}). For Task 1 and Task 5, the subject was instructed to press the R_{11} button (signal in both problems) when he thought there was a movement (Task 1) or a tone (Task 5), and to press the R_{00} button (no signal in either problem) when there was no movement or no tone.

Results

Responses from one session were obtained in the form of a stimulus-response frequency matrix and a similar probability matrix.[1] The response given to a particular pattern can be categorized in two ways. One method of categorization is relative to the auditory problem, the other is relative to the visual problem. In each case, the responses are divided into "signal" and "no signal" responses. If the responses given to the two problems are independent, the frequencies of the "yes" and "no" responses to one problem should suggest nothing about the frequencies of the "yes" and "no" responses to the other problems; i.e., the two categories are orthogonal.

Independence was therefore tested by considering the results of Tasks 2, 3, and 4 in the following manner. The frequencies of the four different responses given by one subject to one stimulus during a session were arranged in the form of 2 x 2 matrix. The rows of such a matrix corresponded to the number of "yes" and to the number of "no" responses given to the auditory problem while the columns corresponded to the number of "yes" and to the number of "no" responses given to the visual problem; thus, the entries of the matrix were the frequencies of the four responses (R_{11}, R_{01}, R_{10}, and R_{00}) given to one stimulus. In this way,

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[1] The probability matrices from experiment 1 are presented in Appendix B.

all the results from one subject were condensed in the form of 36 different matrices. A Chi-square test, with 1 d.f., was then carried out on each of these matrices in order to find whether the four entries were independent of each other. The overall Chi-square value, computed by summing over all values from each subject, was significant for subject 1 at the 0.05 level of confidence; however, the overall Chi-square was not significant for subject 2. Of the 36 individual matrices obtained from the responses of subject 1, only 4 were found to be significant at the 0.05 level and none were significant at the 0.001 level. Thus, it can be said that the Chi-square values[1] obtained were generally non-significant. Those few that were significant can probably be attributed to chance.

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[1] Appendix C contains the tables of Chi-square values and figures of the probability of each response given a particular stimulus.

Theoretical Analysis

If each entry in a probability matrix is denoted by a_{ij}, where a_{ij} is the probability of response j given stimulus i, then for the matrices from Tasks 2, 3, and 4, the probability of hits and false alarms for each problem, can be calculated in the following manner:

For the visual problem,

$$\hat{P}_V(H) = \frac{a_{11.11} + a_{11.01} + a_{01.11} + a_{01.01}}{2}$$

and

$$\hat{P}_V(F.A.) = \frac{a_{10.11} + a_{10.01} + a_{00.11} + a_{00.01}}{2}$$

For the auditory problem,

$$\hat{P}_A(H) = \frac{a_{11.11} + a_{11.01} + a_{10.11} + a_{10.10}}{2}$$

and

$$\hat{P}_A(F.A.) = \frac{a_{01.11} + a_{01.10} + a_{00.10} + a_{00.11}}{2}$$

From the results of Tasks 1 and 5,

$$\hat{P}_V(H) = \frac{a_{11.11} + a_{01.11}}{2} \quad \text{and} \quad \hat{P}_V(F.A.) = \frac{a_{10.11} + a_{00.11}}{2}$$

and

$$\hat{P}_A(H) = \frac{a_{11.11} + a_{10.11}}{2} \quad \text{and} \quad \hat{P}_A(F.A.) = \frac{a_{01.11} + a_{00.11}}{2}$$

Each pair of $\hat{P}(H)$ and $\hat{P}(F.A.)$ values generated by a subject indicates a particular estimate of d', using the equation introduced above,

$$d' = \hat{Z}(F.A.) - \hat{Z}(H)$$

The estimated d' values obtained are shown in Table I, and Figures 4a and 4b, where 'a' and 'b' denote subjects 1 and 2 respectively. From the distributions of the d' values there seems to be little deviation in the magnitudes of the auditory d' and visual d'values associated with the task required of the subject, (the degree to which he is asked to attend to a particular modality). The auditory and visual d' values calculated from Tasks 1 and 5 are not significantly different from those values obtained when the subject attempts both problems simultaneously. It can also be seen in the figures from Tasks 2, 3, and 4 that although sensitivity fluctuates from session to session, the variation is reflected in the responses to both problems: e.g., an increase in visual sensitivity is often accompanied by an increase in the auditory d' value, and not a decrease. Thus, there appears to be no reciprocal relation between the auditory and visual sensitivity measures, since, if such a relation existed, an increase in the value of the d' from one problem should be accompanied by a decrease in the d' value from the other problem.

Table 1

Table of d'values obtained from the $\hat{P}$. (Hits) and $\hat{P}$. (False Alarms) made in response to the visual problem, and to the auditory problem.

Subject 1

Task	1		2		3		4		5	
Session	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v
1	-	1.54	1.82	0.95	1.87	0.78	2.48	1.54	2.48	-
2	-	1.32	2.57	1.52	3.11	1.51	2.75	1.12	3.11	-
3	-	1.69	2.74	1.36	2.82	1.30	3.28	1.19	3.43	-
Mean	-	1.52	2.38	1.28	2.60	1.20	2.84	1.28	3.00	-

Subject 2

Task	1		2		3		4		5	
Session	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v
1	-	1.22	2.20	0.94	2.76	0.81	1.08	0.59	2.33	-
2	-	1.28	2.83	1.02	2.38	1.32	2.68	1.07	2.76	-
3	-	0.59	2.46	0.80	2.72	1.06	3.15	0.69	2.68	-
Mean	-	1.03	2.50	0.92	2.62	1.06	2.30	0.78	2.59	-

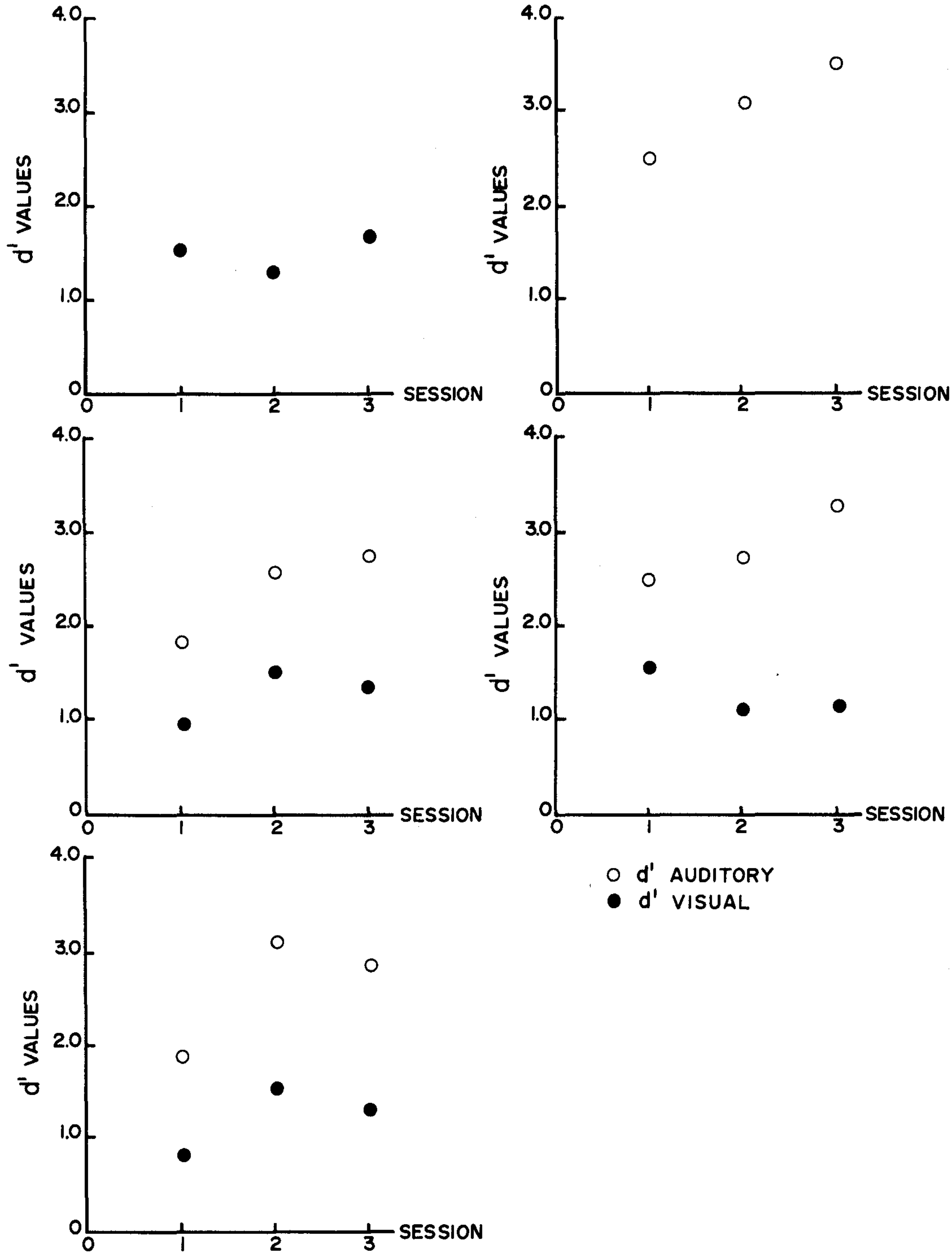

Fig. 4a. The d' value(s) obtained from each session for each of the five tasks. Subject 1

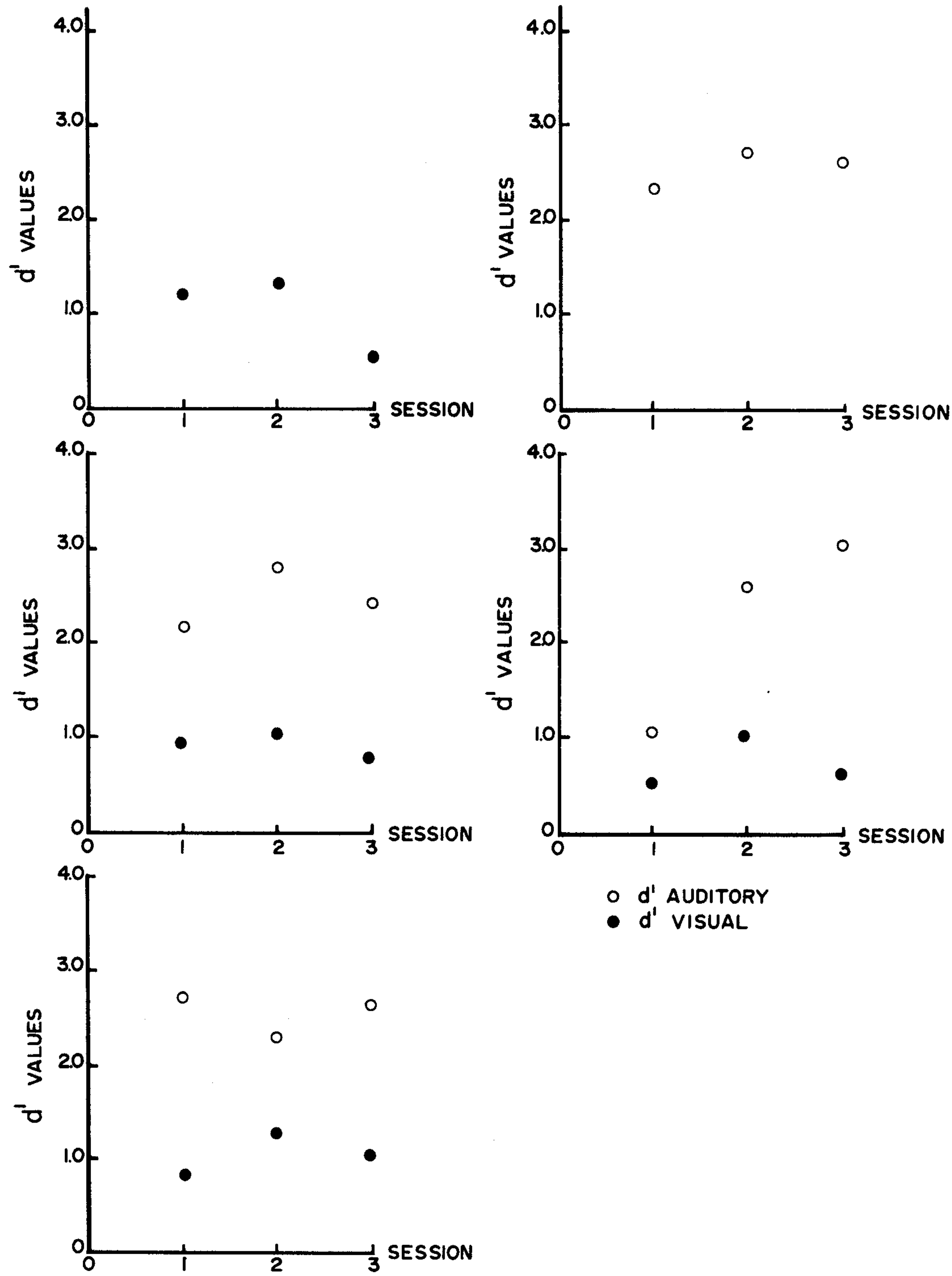

Fig. 4b. The d' value(s) obtained from each session for each of the five tasks. Subject 2

Experiment Two

The results of experiment 1 suggest that simultaneous performance on the two problems differs, at the most, only slightly from performance on the problems individually. Therefore, instructions asking for degrees of "attention" to the two individual problems are not likely to produce measurable changes. Accordingly, a second experiment was designed which focused specifically on the question of whether performances on the two problems were independent. Only three sets of instructions[1] were used: two sets of instructions involving responses to one problem only (Tasks 1 and 5 in experiment 1), and a set of instructions requesting responses to both problems simultaneously (Task 3 in experiment 1).

Since it was possible that the relative ease of the two problems might influence the results obtained (in the first experiment, the subjects consistently obtained a higher auditory d' than visual d' measure ; they found the auditory problem easier than the visual) two interlight intervals were used in experiment 2. In the earlier section entitled Discriminative Theory, theoretical expressions were considered which indicate how the visual and auditory d' values should change when the interlight interval (t) is manipulated.

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[1] The instructions for experiment 2 are presented in Appendix D.

The actual values for this time were chosen such that, theoretically, the d' values at both times, for both problems, would fall between d' = 0.5 and d' = 2.56, the percentage correct then being between 60% and 90%. These limits were chosen in order to insure good estimates of d'. The durations were fixed at two seconds and a half second, the amplitude of the tone and the lateral separation of the lights being set individually for each subject such that the d' values fall between the limits, at both of these interlight durations.

From the previous theoretical expressions (Eqs. 5 and 6), it can be seen that the visual problem is likely to be easier than the auditory at the half second interlight interval, and vice versa for the two seconds condition.

Apparatus and Procedure

Subjects 1 and 2 were the two subjects from experiment 1, while subject 3 was new. They were employed on the same basis as in the first experiment. All three subjects had six practice sessions of 200 trials at each interlight interval; subject 1 and 2 then completed 18 similar daily sessions and subject 3 completed 21 sessions.

The procedure was the same as in experiment 1 except that m (the separation between lights on signal trials) was set at 0.356, 0.300 and 0.118 degrees visual angle for subjects 1, 2, and 3 respectively. To ensure that the auditory d' values, at both (t) observation periods, fell within the limits previously noted, the amplitude of the tone was slightly modified (from experiment 1) for each of the three subjects. It was found that subject 1 required the highest amplitude value, subject 3 a slightly lower value and subject 2 the least value. However, the signal to noise ratio remained approximately 20 for all three subjects.

Before the beginning of each session, the subject read the general instructions plus those pertaining to one of the three tasks. He was then told at which of the interlight times, either two seconds or a half-second, he would first attempt the task. The subject was seated in the dark room at a distance of 4.35 meters from the visual display, and presented with 48 practice trials which had the first interlight value. After completion of the practice trials, two blocks of 100 trials, having the same interval, were attempted. The subject then completed 48 practice trials followed by 200 experimental trials at the other interlight interval. The frequency and probability results[1] were obtained separately for the two interlight conditions. The order of the two interlight times within and between tasks was randomized.

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[1] The probability matrices from experiment 2 are presented in Appendix E.

Results

To test whether performance on one problem is independent of performance on the other problem (when both problems are attempted simultaneously), the Chi-square test described in the result section of experiment 1 was calculated.[1] The frequencies of the four responses (R_{11}, R_{01}, R_{10}, R_{00}) given to one stimulus pattern in 200 trials generated one matrix and thus, one Chi-square value with one degree of freedom. For subjects 1 and 2, there were a total of 24 of these frequency matrices (summing over stimuli and sessions) for each of the two values of the interlight interval; for subject 3, there were 28 matrices for each of the time conditions. Summing all the Chi-square values obtained from one subject, at one of the interval times, gives an overall Chi-square with 24 degrees of freedom (subjects 1 and 2), or with 28 degrees of freedom (subject 3). It was found that for the condition in which $t = \frac{1}{2}$, the overall Chi-square value was non-significant at even the 0.05 level for each of the three subjects. The overall Chi-square value, calculated from trials in which $t = 2$, was also non-significant for subjects 2 and 3, but was significant at the 0.05 level for subject 1. However, there were only 3 significant values in the 24 Chi-squares producing the one significant overall Chi-square. Thus, the present results appear to support the previous finding of little inter-

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[1] The Chi-square values are presented in Appendix F.

action between responses to the two problems.

Several homogeneity tests[2] were evaluated to see if the visual and/or auditory performance was, in any way, dependent upon whether the two problems were attempted separately or simultaneously. There were four homogeneity tests for each subject, i.e., for performance on the visual and for performance on the auditory problem at each of the interlight interval durations. Each frequency matrix from Tasks 1 and 5 may be collapsed into a square matrix in which the rows correspond to 'signal' and 'no signal' stimuli, and the columns to the responses associated with these. Similarly, a frequency matrix from trials on which both problems are attempted may be regarded as two separate stimulus-response matrices, one for each problem. The matrices compared in the homogeneity test were produced by summing, over sessions, the frequencies in each of the cells of the stimulus-response matrices. The matrix from Task 1 or 5 was compared with the appropriate matrix from the two problem task. Assuming the null hypothesis (i.e., of one process generating both matrices) to be true, the best estimate of the expected frequency in a particular cell is the average of frequencies in corresponding cells of the two matrices being compared. The Chi-square values obtained from these tests, each having 2 degrees of freedom, are presented in Table 2. None of the values were significant at the 0.05 level for subject 1; the value obtained from the ½ second visual problem comparison was the only one significant for subject 2, but for subject 3, the auditory problem comparison was significant for both interlight

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[2] See Suppes and Atkinson, 1960, for a discussion of this type of Chi-Square test.

Table 2

X^2 values obtained from the Homogeneity Test

Interlight Interval: t = 0.5 sec.

	Visual Problem	Auditory Problem
Subject 1	2.760	0.018
Subject 2	8.864*	1.086
Subject 3	3.368	12.067*

Interlight Interval: t = 2 sec.

	Visual Problem	Auditory Problem
Subject 1	1.106	3.006
Subject 2	0.830	0.510
Subject 3	0.898	54.371*

* - significant at the 0.05 level.

intervals. Apart from some peculiar effect on the auditory performance of subject 3, visual and auditory performance, at both time values, do not appear to be affected by working on the two problems simultaneously.

Theoretical Analysis and Discussion

The probabilities of Hits and False Alarms were calculated from the probability matrices, as in experiment 1, and the d' values, presented in Table 3, were obtained from these probabilities. The visual and auditory d' values are displayed on Figs. 5a, 5b, and 5c, the values from Tasks 1 or 5 are plotted on the same graph as the visual or auditory d' value obtained from Task 3. From these figures, it appears that the values obtained from sessions in which only one problem was attempted are generally similar to those obtained when both problems are attempted. This suggests that visual and auditory sensitivity are essentially independent of each other. However, for subject 3, there appears to be a consistent discrepancy between the auditory d' values obtained from Task 3 and those obtained from Task 5, particularly for the trials having an observation interval of two seconds. The difference in d' values suggests that the significant homogeneity results, calculated from this subject's auditory data on the two tasks, was a result of a change in sensitivity and not response bias.

For each subject, the ratio of the d' values, obtained from trials with an interlight interval of a half second and from trials with an interval of two seconds, was calculated to see if it approximated the predictions made by the Kinchla and Smyzer model and by Signal Detection Theory. Specifically, Equation 6 predicts that the magnitude of the visual d' from the two second condition should be one half that

Table 3

d' values calculated from the $\hat{P}$. (Hits) and $\hat{P}$. (False Alarms) made in response to the visual problem and to the auditory problem

Subject 1

Interlight Interval:	0.5 sec.						2 sec.					
Task	1		3		5		1		3		5	
Session	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v
1	---	2.07	1.00	1.60	1.21	---	---	0.49	1.64	0.41	2.26	---
2	---	1.61	0.62	1.19	1.00	---	---	0.48	1.85	0.60	1.96	---
3	---	2.46	1.14	1.72	0.99	---	---	0.26	1.51	0.62	1.76	---
4	---	1.62	1.08	2.18	1.16	---	---	0.36	0.96	0.66	2.08	---
5	---	1.76	0.86	1.83	0.79	---	---	0.58	1.33	0.62	1.78	---
6	---	1.38	0.88	1.95	0.70	---	---	0.25	2.18	0.49	2.32	---
Mean		1.82	0.93	1.75	0.98			0.40	1.58	0.57	2.03	

Subject 2

Interlight Interval:	0.5 sec.						2 sec.					
Task	1		3		5		1		3		5	
Session	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v
1	---	1.77	0.18	1.88	0.84	---	---	0.61	1.06	0.56	1.88	---
2	---	2.08	0.46	1.81	0.76	---	---	0.42	1.54	0.28	2.08	---
3	---	3.10	0.70	2.25	0.31	---	---	0.58	1.34	0.52	1.18	---
4	---	2.56	0.52	1.56	0.56	---	---	0.54	1.57	0.56	1.69	---
5	---	2.74	0.83	2.66	0.58	---	---	1.05	1.70	0.66	1.84	---
6	---	2.80	0.92	2.05	0.80	---	---	0.42	1.76	0.31	1.54	---
Mean		2.51	0.60	2.04	0.64			0.60	1.50	0.48	1.70	

Subject 3

Interlight Interval:	0.5 sec.						2 sec.					
Task	1		3		5		1		3		5	
Session	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v	d'a	d'v
1	---	1.85	0.10	1.74	0.51	---	---	0.38	0.54	0.28	0.86	---
2	---	1.56	0.26	1.13	0.88	---	---	0.26	0.20	0.10	1.63	---
3	---	2.18	0.13	1.64	1.35	---	---	0.82	1.06	0.05	2.01	---
4	---	1.54	0.38	1.65	0.72	---	---	0.23	1.40	0.58	1.98	---
5	---	1.52	0.84	1.38	1.08	---	---	0.71	1.62	0.48	2.64	---
6	---	1.58	0.96	1.52	0.44	---	---	0.34	1.32	0.48	2.40	---
7	---	1.62	0.64	1.98	0.60	---	---	0.34	2.44	0.44	1.87	---
Mean		1.69	0.47	1.58	0.78			0.44	1.23	0.34	1.91	

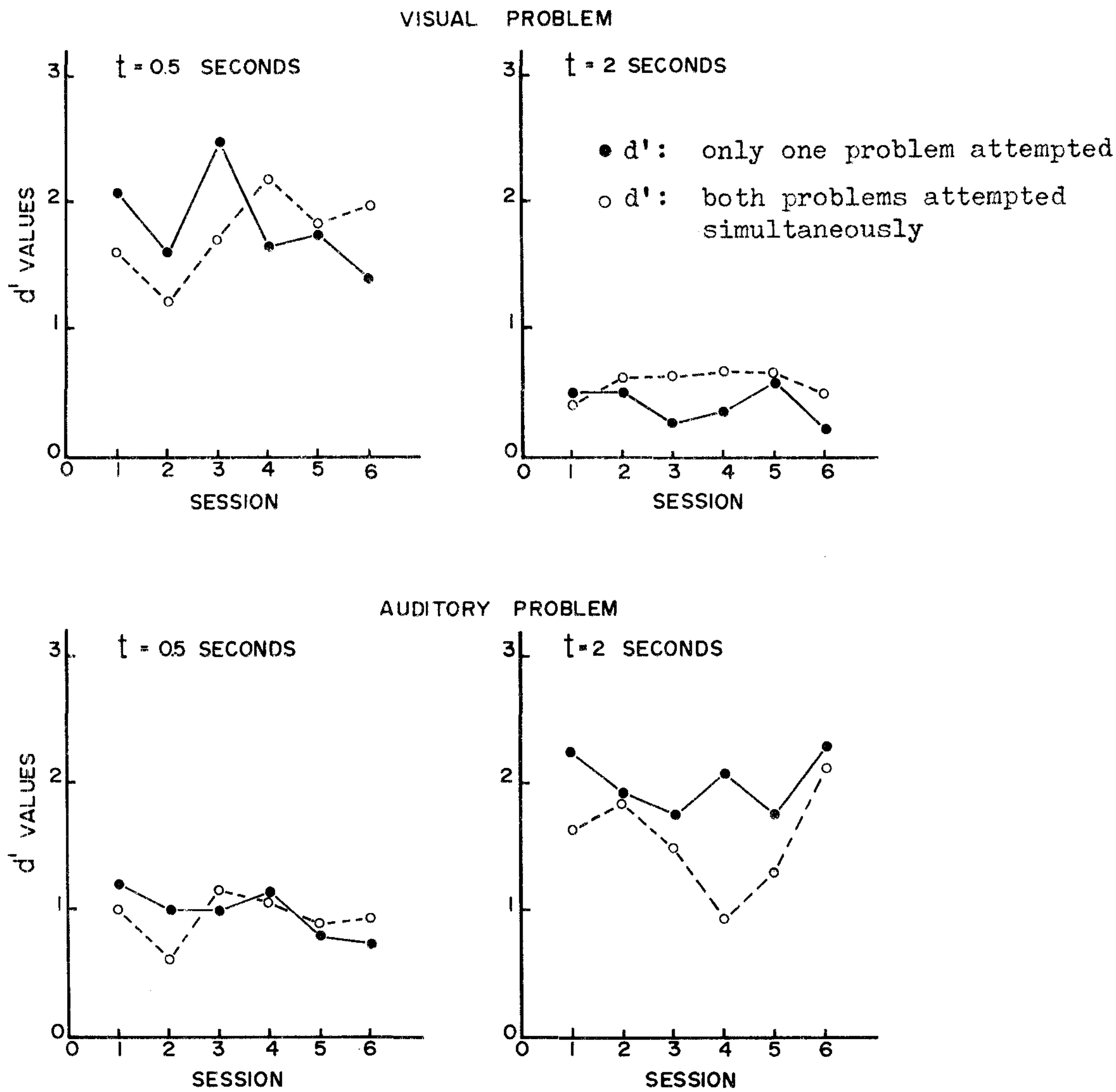

Fig. 5a. Visual and Auditory d' Values. Subject 1

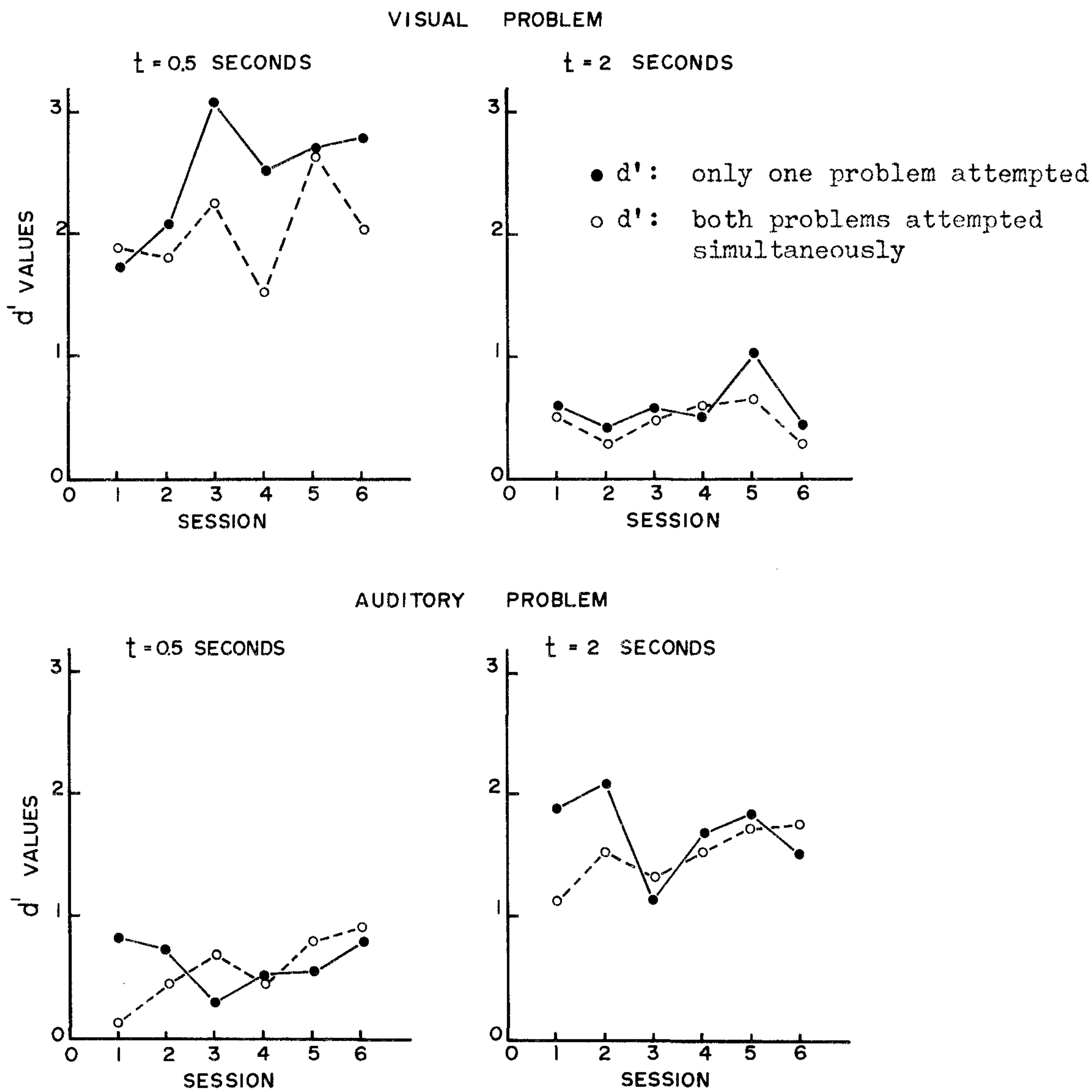

Fig. 5b. Visual and Auditory d' Values. Subject 2

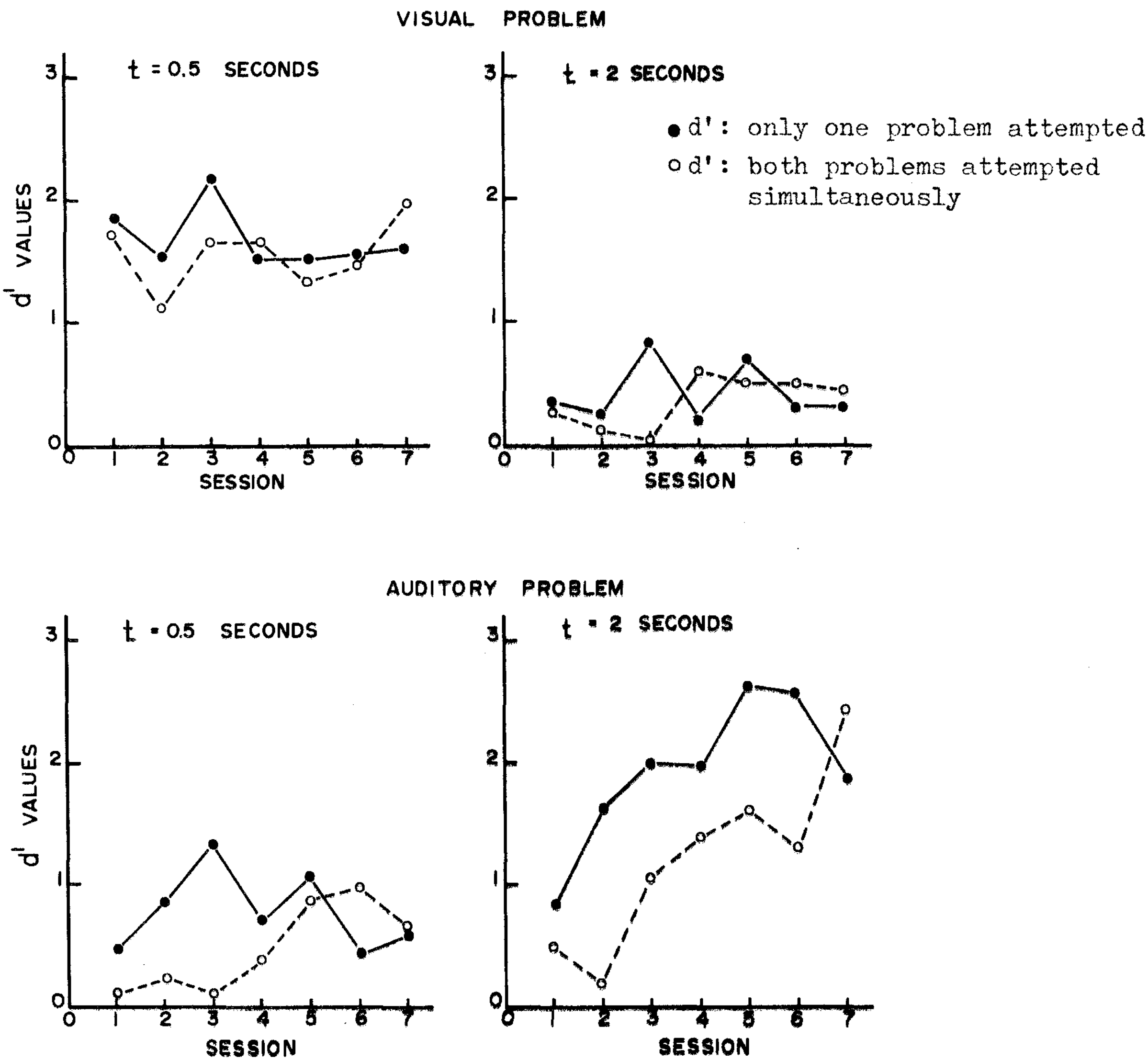

Fig. 5c. Visual and Auditory d' Values. Subject 3

of the d' from the half second condition; Equation 7 predicts that the auditory d' value from the two seconds condition should be twice the d' value from the half second condition. Using only the d' values obtained on Tasks 1 and 5, one visual and one auditory ratio were obtained from each subject's results such that the sum of the squared deviations, between this ratio and the ratios from each session, was at a minimum. This is equivalent to finding the best fitting straight line on a graph of d' at two seconds against d' at a half second, where each point represents the values obtained during one session, and with the restriction that the line passes through zero. The ratios obtained for each subject are presented in Table 4. The visual and auditory ratios were similar for all three subjects. Those calculated from the auditory d' values were of approximately the magnitude predicted by Signal Detection Theory, but the ratios of the visual d' values differed greatly from the predicted ratio of a half.

If, as the model of movement recognition assumes, the d' value is a linear function of the square root of the time (t) between the standard and comparison stimuli then a graph, of time (t) against variance of the sensory distribution, should result in a straight line passing through zero. The variance (σ_t^2) was calculated from Equation 1, the difference in the means of the S_1 and S_0 distributions being equal to the separation of the lights in degrees visual angle, and a graph of variance against time (Figure 6) drawn for each subject's results. It can be seen that the lines connecting the two points obtained from one

Table 4

Ratios of the d'values from t = 2 sec. condition to the d'values from t = 0.5 sec. condition

Subject Number	Auditory Ratio	Visual Ratio
1	2.012	0.213
2	2.536	0.236
3	2.167	0.265

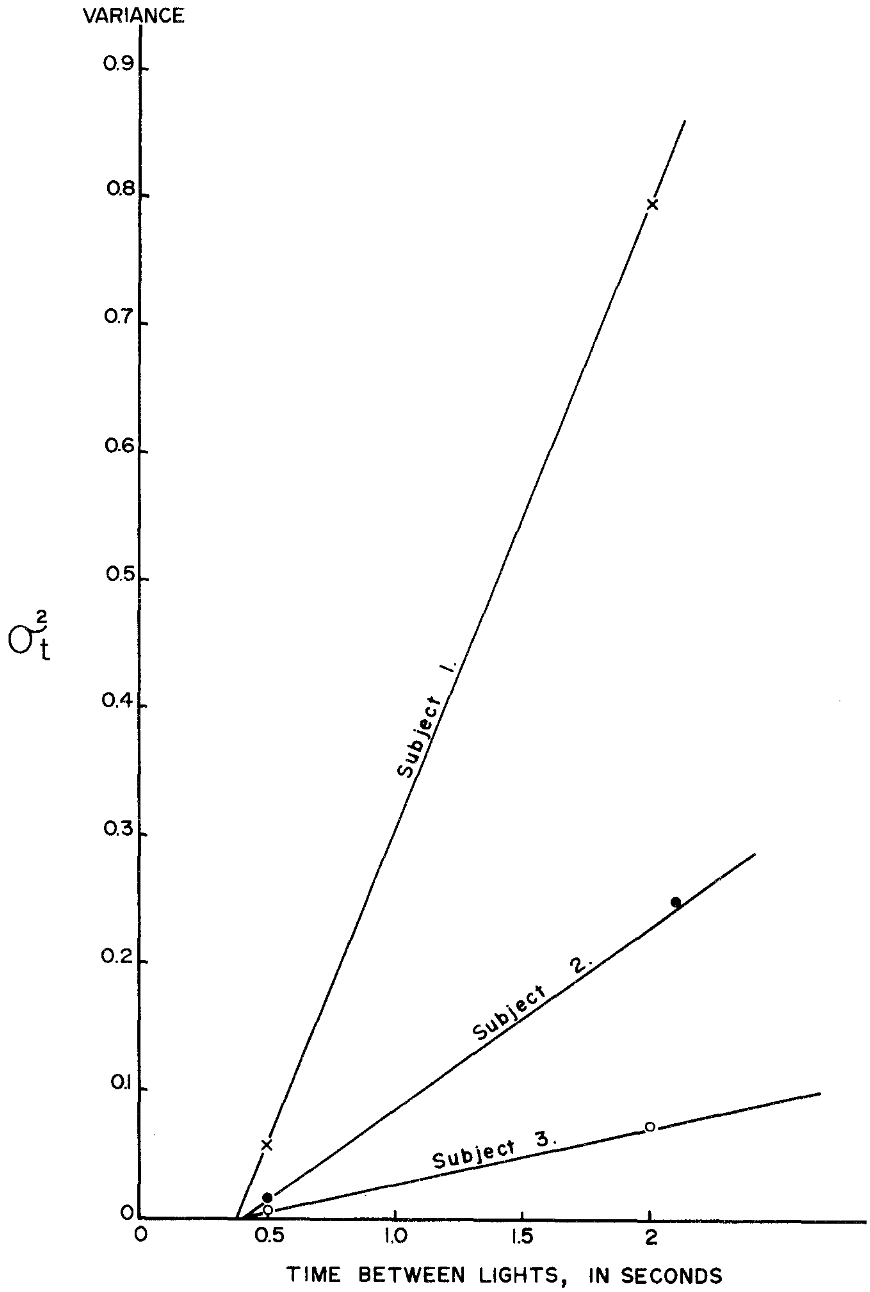

Fig. 6. Variance of the Sensory Distribution against Time

subject do not pass through zero but are such that the variance is zero at a positive time value. This is a surprising result since a previous study by Keller and Kinchla, 1968, employing interlight times of 0.5, 1.0, and 2 seconds, clearly supported the predicted relation between d' value and time (t). The major difference between that study and Task 1 of the present one was the presence of continuous white noise in the latter. Because of this, the beginnings of the trials differed: in the Keller and Kinchla study, a trial began with the presentation of a 1000 Hz. auditory warning signal followed by the standard light of 100 msec. duration. However, in the present study, a new trial was only indicated by a longer standard stimulus (1000 msec.). No further attempt will be made to interpret this discrepancy between the present results and those of Keller and Kinchla.

Conclusions

From the results of the two experiments, it may be concluded that there seems to be surprisingly little interaction between visual and auditory performance when the subject attempts to work on both problems simultaneously; also, that the visual and auditory sensitivities (with the exception of the auditory sensitivity of subject 3) were not dependent upon whether the problems were attempted simultaneously or separately.

It might be argued that the subjects were unable to ignore the other problem during tasks which required responses to only one problem, and therefore, "attention" was always divided between both auditory and visual stimuli whether the subject was requested to respond to the problems simultaneously or not. Alternatively, the results might be interpreted to indicate that retention of a position in space is a passive form of memory.

Although the type of memory studied in these experiments is functionally similar to other forms of sensory memory, in that retention deteriorates with time, it is possible that the processes of retaining information differ. For example, visual position memory may be primarily a peripheral or receptor process whereas brightness (or size) memory may be a central process. Thus, further studies involving other types of sensory memory seem to be called for.

Variability in the effect of interpolated tasks on different types of memory is not unlikely since this has already been found in the previously described study of retroactive interference by Posner (1968). The present experimental evidence indicates only that performance on an auditory detection problem and performance on a visual recognition problem are essentially independent of each other.

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Appendix A

Instructions

This is an experiment concerned with perception. There are five different tasks which will be asked of you. On any one day, you will only be presented with the instructions pertaining to the one task for that day.

The room will be darkened during the experiment; on each trial, a light will flash in front of you. A short constant time later, there will be a briefer flash. On a randomly-selected half of the series of trials, this latter flash will occur in the same position as the first, and on the other half, the light will move to the right by a constant amount.

During the entire experiment, you will hear noise through the earphones. On a randomly-selected half of the trials, there will be the noise plus a tone for the period between the two light flashes, and on the other half, the noise will remain the same, i.e., without the addition of a tone.

At the beginning of each session you will be given a practice block of 48 such trials; then, you will be presented with 400 trials. These trials will be divided into 4 'blocks' such that there are 100 trials in each. At the end of each block, you will have a one-minute rest period before the start of the next block. You must stay in the dark room for the whole session, i.e., for the 400 trials and the rest periods. There will be no warning signal to denote when a new block is about to begin; therefore, if you miss the first trial of a block, do not worry but continue with the rest of the trials. The trials on which the light and/or sound change are randomly and independently ordered for each block of 100 trials.

You will be seated in a chair which has 4 buttons on its right arm. Respond by pressing specific buttons; which ones will depend on the task which you are doing that day. The response must be made as soon as possible after the second flash of light. Once you have pressed the particular button, never change your mind and press one of the others. A response must be made on every trial even if this means guessing.

Are there any questions?

Task 1

Respond only to the visual stimulus. You will hear the noise through the earphones but you are not required to make any decision as to whether a tone is added to the noise. Press the left top button if you think that the light has changed position. Press the right bottom if you decide that it has not.

Remember that the second flash will be in a different position on a randomly-selected one-half of the trials in any given block.

Task 2

Concentrate on the visual stimulus. It is your task to decide whether the second flash was in the same position as the first or not.

Although it is important that you do as well as possible on the visual problem, you should also make a decision about whether the tone was added to the noise or not.

Press the top left button for: light changed position and tone added.

Press the bottom right button for: light remained in the same position and no tone change.

Press the top right button for: tone added and light remained in the same position.

Press the bottom left button for: light changed position but no tone added.

Remember that the sound and light changes occur randomly and independently on one-half of the trials in any given block.

Task 3

Pay equal attention to the visual and auditory problems. Attempt to achieve a correct decision on both problems on each trial.

Responses for each decision are as follows:

Press the top left button for: light changed position and tone added.

Press the bottom right button for: light remained in the same position and no tone.

Press the top right button for: light remained in the same position and tone added.

Press the bottom left button for: light changed position but tone not added.

Remember that the sound and light changes occur randomly and independently on one-half of the trials in any given block.

Task 4

Concentrate on the auditory stimulus. It is your task to decide whether a tone was present during the interflash period or not. Although it is important that you do as well as possible on the auditory problem, you should also make a decision about whether the second flash of light was in the same or in a different position from the first.

Press the top left button for: light changed position and tone added.

Press the bottom right button for: light remained in the same position and no tone.

Press the top right button for: light remained in the same position and tone added.

Press the bottom left button for: light changed position but tone not added.

Remember that the sound and light changes occur randomly and independently on one-half of the trials in any given block.

Task 5

Respond only to the auditory stimulus. The first light flash will denote the beginning of the period during which the tone may be added to the noise. The second flash of light denotes the end of this period and the beginning of the response interval. If you decide that the tone was present, press the top left button; press the bottom right button if you think it was not.

Remember that the tone occurs randomly on one-half of the trials in any given block.

Appendix B

Probability Matrices for Subject 1

Task 1 (Respond to visual problem only)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	788	000	000	222	677	000	000	323	730	000	000	270
S_{01}	770	000	000	230	750	000	000	250	800	000	000	200
S_{10}	220	000	000	780	192	000	000	808	190	000	000	810
S_{00}	194	000	000	806	250	000	000	750	153	000	000	847

Task 2 (Concentrate on visual problem)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	545	131	313	010	640	090	230	040	541	020	418	020
S_{01}	020	788	030	162	051	687	051	212	020	566	040	374
S_{10}	144	021	649	186	152	020	788	040	121	000	859	020
S_{00}	000	235	010	755	000	190	120	690	020	173	082	724

Task 3 (Equal Attention)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	394	192	354	061	697	040	242	020	580	040	370	010
S_{01}	030	580	010	380	020	798	030	152	091	657	020	232
S_{10}	090	101	636	172	170	020	780	030	150	010	790	050
S_{00}	010	394	051	545	010	255	071	663	010	230	110	650

Task 4 (Concentrate on auditory problem)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	630	040	310	020	444	030	475	051	610	060	290	040
S_{01}	070	580	090	260	030	550	040	380	040	690	040	230
S_{10}	091	020	818	071	120	000	820	060	150	020	770	060
S_{00}	000	152	111	737	030	150	090	730	020	200	060	720

Task 5 (Respond to auditory problem only)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	850	000	000	150	930	000	000	070	970	000	000	030
S_{01}	090	000	000	910	090	000	000	910	070	000	000	930
S_{10}	860	000	000	140	980	000	000	020	970	000	000	030
S_{00}	060	000	000	940	060	000	000	940	051	000	000	949

Probability Matrices for Subject 2

Task 1 (Respond to visual problem only)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	818	000	000	182	690	000	000	310	570	000	000	430
S_{01}	770	000	000	230	800	000	000	200	560	000	000	440
S_{10}	354	000	000	646	270	000	000	730	360	000	000	640
S_{00}	330	000	000	670	260	000	000	740	310	000	000	690

Task 2 (Concentrate on visual problem)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	510	100	310	080	590	170	190	050	600	090	270	040
S_{01}	030	616	020	333	020	650	020	310	070	550	030	350
S_{10}	330	040	490	140	230	090	620	060	242	030	646	081
S_{00}	020	140	040	800	040	370	010	580	030	390	070	510

Task 3 (Equal Attention)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	590	120	240	050	560	170	200	070	540	090	330	040
S_{01}	030	720	000	250	020	707	000	273	040	520	010	430
S_{10}	340	120	440	100	200	070	570	160	143	031	694	133
S_{00}	010	370	020	600	020	180	050	750	020	230	020	730

Task 4 (Concentrate on auditory problem)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	670	100	170	060	520	100	310	070	530	030	390	050
S_{01}	120	530	070	280	040	510	010	440	080	570	040	310
S_{10}	320	040	520	120	130	020	730	120	360	040	570	030
S_{00}	070	240	140	550	010	232	030	727	040	230	000	730

Task 5 (Respond to auditory problem only)

	Session 1				Session 2				Session 3			
	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	620	000	000	380	810	000	000	190	800	000	000	200
S_{01}	030	000	000	970	030	000	000	970	050	000	000	950
S_{10}	820	000	000	180	810	000	000	190	900	000	000	100
S_{00}	050	000	000	950	030	000	000	970	051	000	000	949

Appendix C

Subject 1

X^2 values calculated to test whether responses on the visual problem are independent of responses on the auditory problem

Task 2: Concentrate on the visual problem

Session	1	2	3	Total over Sessions (3df)
S_{11}	4.7360*	0.1077	0.0609	4.9046
S_{01}	5.6510	3.2235	1.6900	10.5654*
S_{10}	0.6851	1.1740	0.2783	2.1374
S_{00}	0.3098	3.1986	0.0026	3.5110
Total over Stimuli (4df)	11.3819*	7.7038	2.0318	21.1175* Total (12df)

Task 3: Equal attention to both problems

Session	1	2	3	Total over Sessions (3df)
S_{11}	4.1743*	0.1628	0.7238	5.0609
S_{01}	0.3433	6.1804*	0.3294	6.8531
S_{10}	7.6300*	1.5081	0.0021	9.1402*
S_{00}	1.4865	0.8766	1.8351	7.1982
Total over Stimuli (4df)	13.6341*	8.7279	2.8904	25.2524* Total (12df)

Task 4: Concentrate on the auditory problem

Session	1	2	3	Total over Sessions (3df)
S_{11}	0.0032	0.3490	0.2460	0.5953
S_{01}	3.7813	0.7085	2.3340	6.8238
S_{10}	1.2375	0.8704	0.3944	2.5023
S_{00}	2.2155	0.4527	0.0456	2.7138
Total over Stimuli (4df)	7.2346	2.3806	3.0200	12.6352 Total (12df)

Overall Total: 59.005 (36df)

* X^2 values at significant level >.05

Subject 2

X^2 values calculated to test whether responses on the visual problem are independent of responses on the auditory problem

Task 2: Concentrate on the visual problem

Session	1	2	3	Total over Sessions (3df)
S_{11}	0.1794	0.0247	0.0003	0.2044
S_{01}	0.6711	0.5445	0.3019	1.5175
S_{10}	2.0520	6.3600*	0.0000	8.4120*
S_{00}	4.1330*	3.3100	0.7876	8.2306*
Total over Stimuli (4df)	7.0355	10.2392*	1.0898	18.3645 Total (12df)

Task 3: Equal attention to both problems

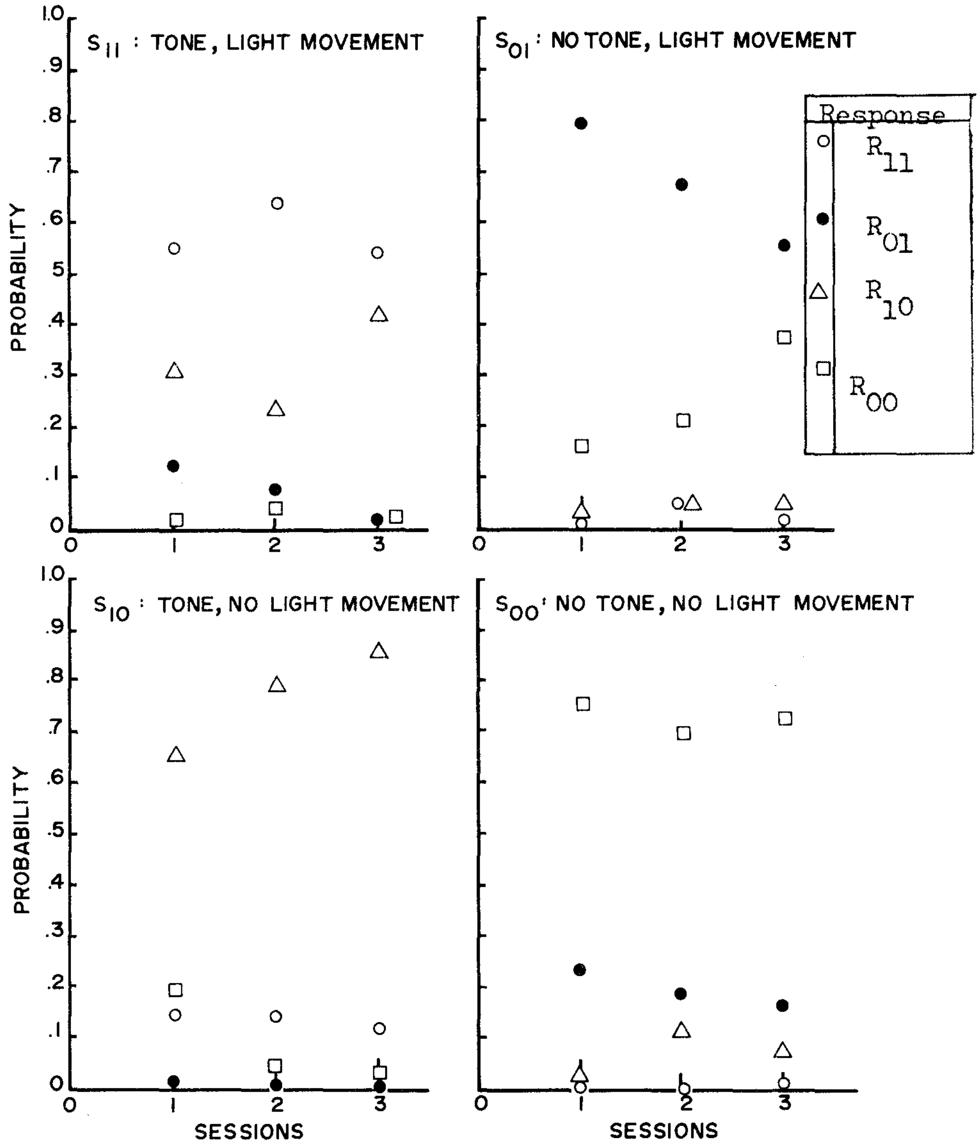
Session	1	2	3	Total over Sessions (3df)
S_{11}	0.0017	0.0752	0.2489	0.3258
S_{01}	1.0310	0.7743	1.2303	3.0356
S_{10}	0.8292	0.1788	0.0277	1.0357
S_{00}	0.0286	0.3456	1.9119	2.2861
Total over Stimuli (4df)	1.8905	1.3739	3.4188	6.6832 Total (12df)

Task 4: Concentrate on the auditory problem

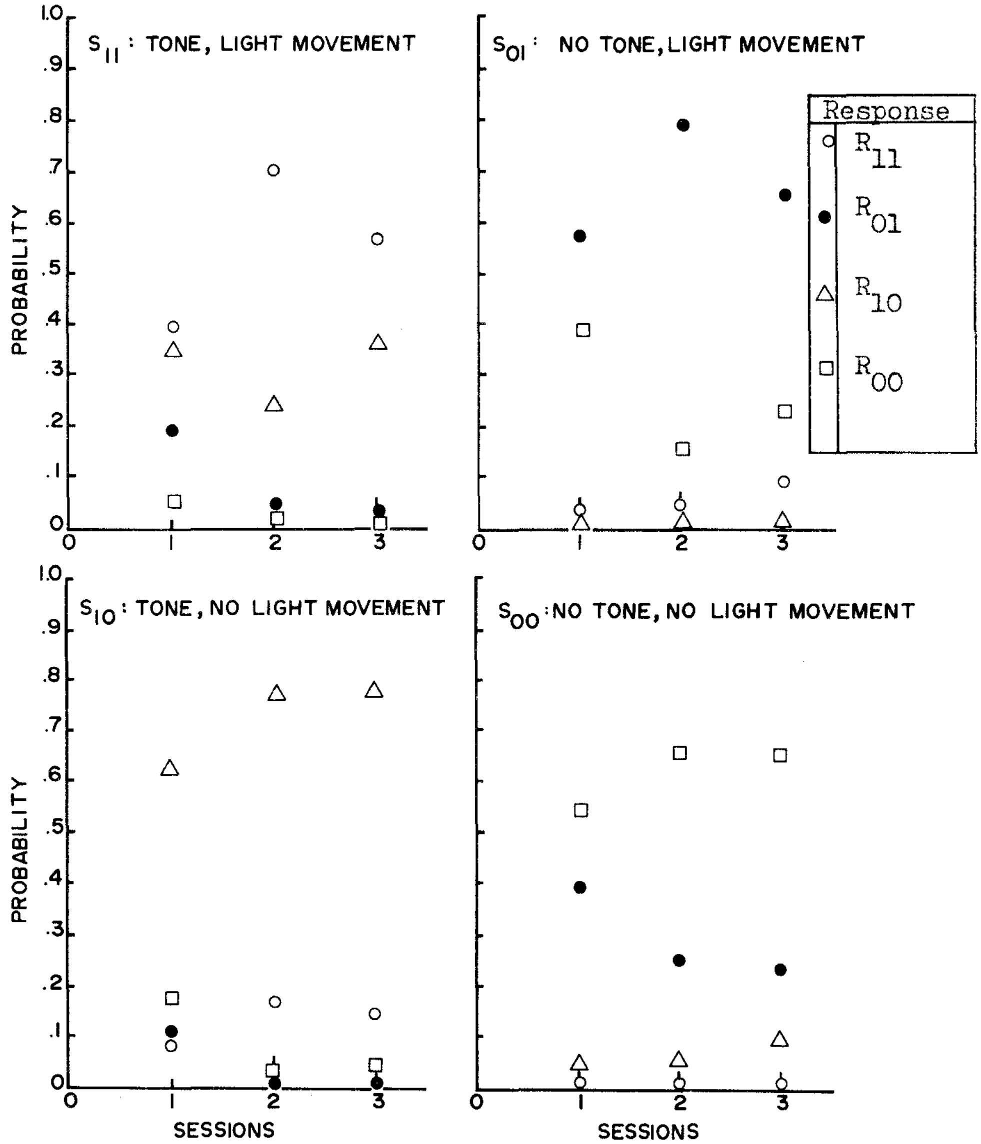
Session	1	2	3	Total over Sessions (3df)
S_{11}	2.2611	0.0877	1.2078	3.5566
S_{01}	0.0350	1.3291	0.0167	1.3808
S_{10}	1.0002	0.0065	0.9216	1.9283
S_{00}	0.0677	0.0013	11.2650*	11.3340
Total over Stimuli (4df)	3.3604	1.4246	13.4111*	18.1997 Total (12df)

Overall Total: 43.247 (36df)

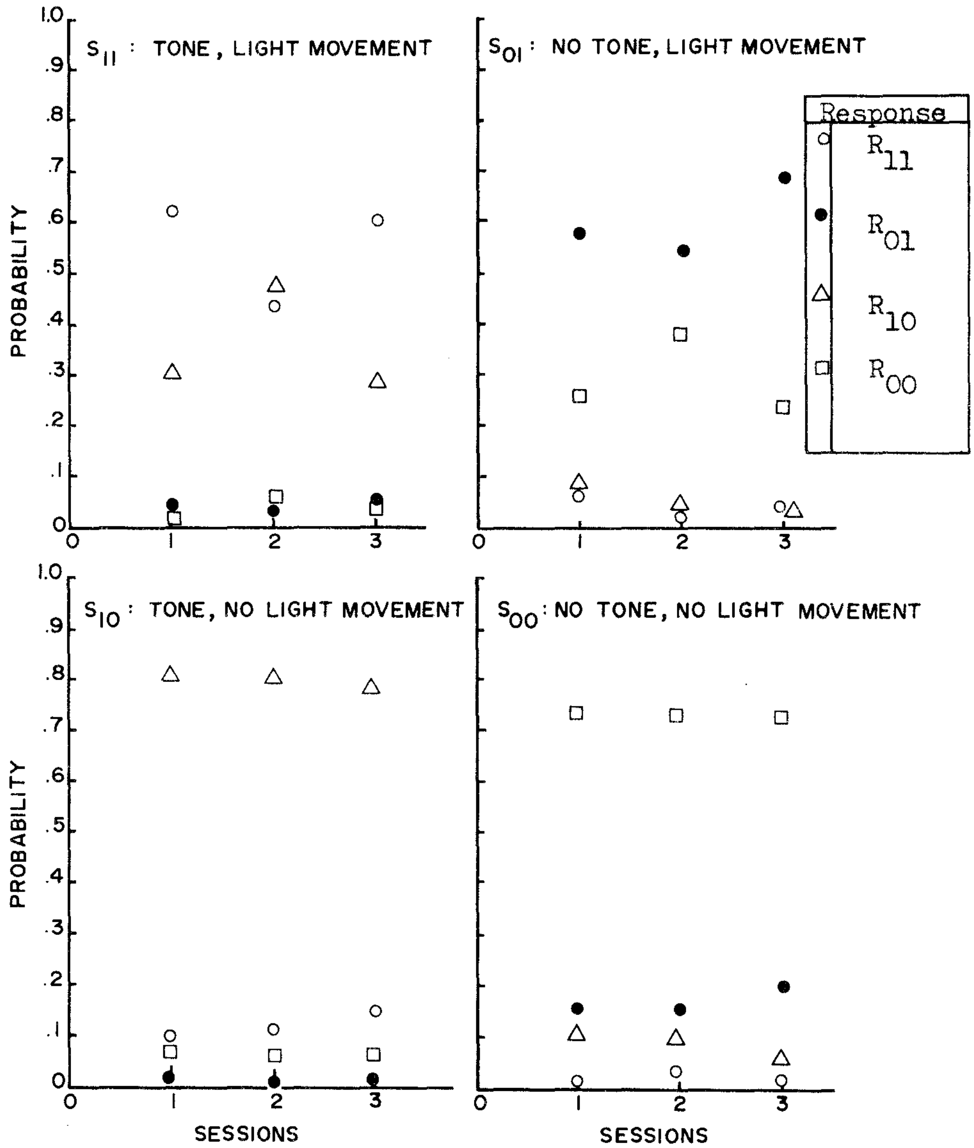
* X^2 values at significant level $>.05$



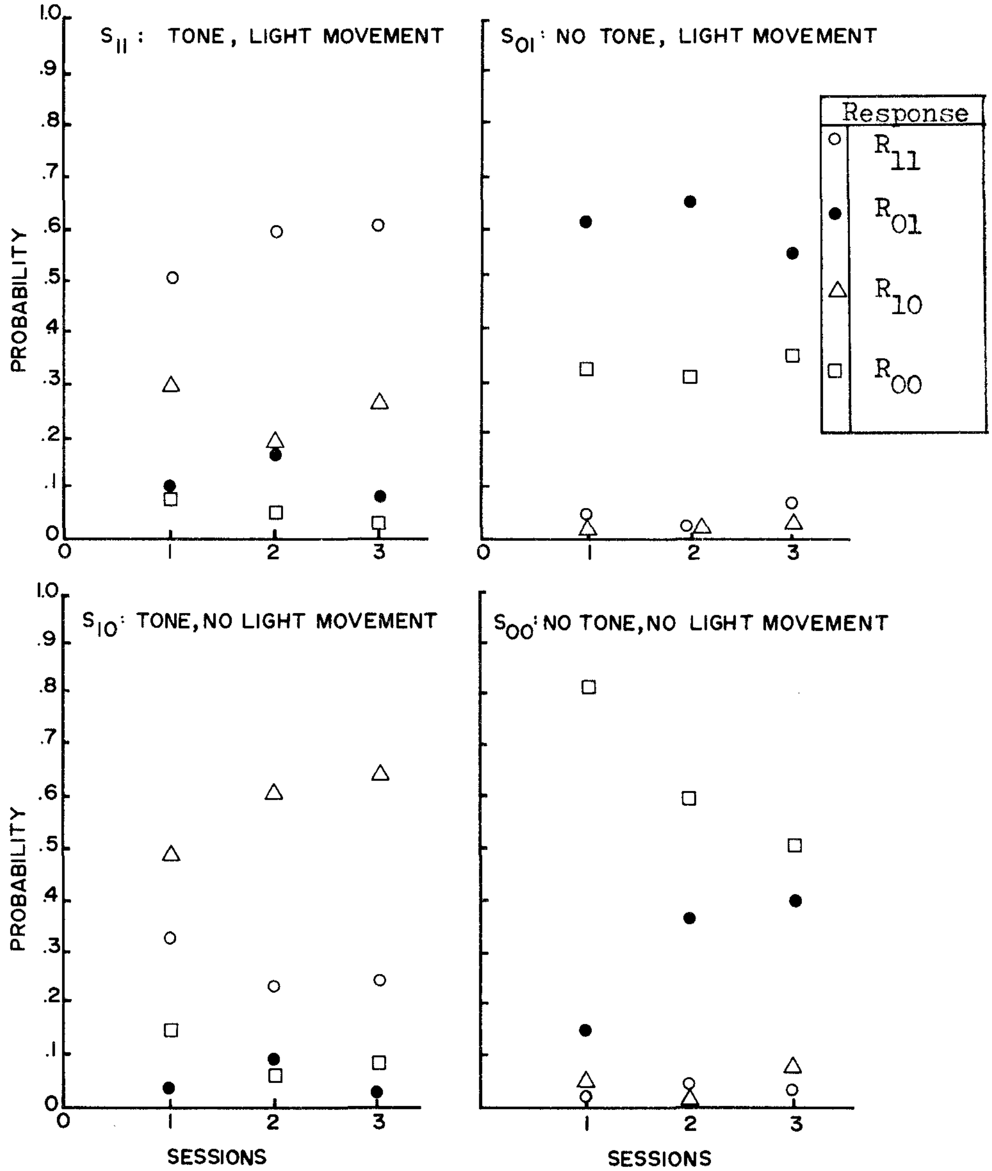
Conditional probabilities of the four responses, for each stimulus in Task 2. Subject 1



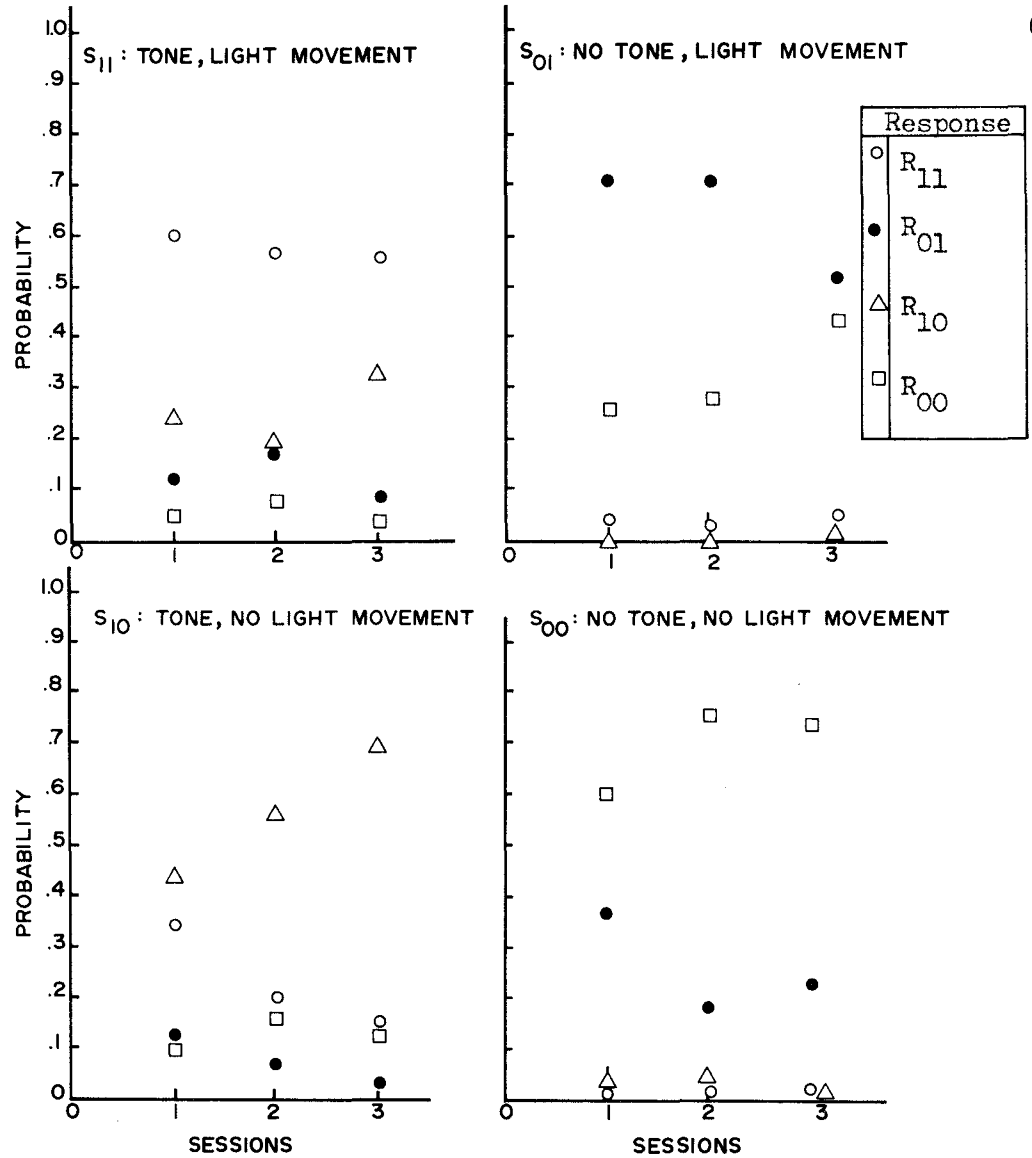
Conditional probabilities of the four responses, for each stimulus in Task 3. Subject 1



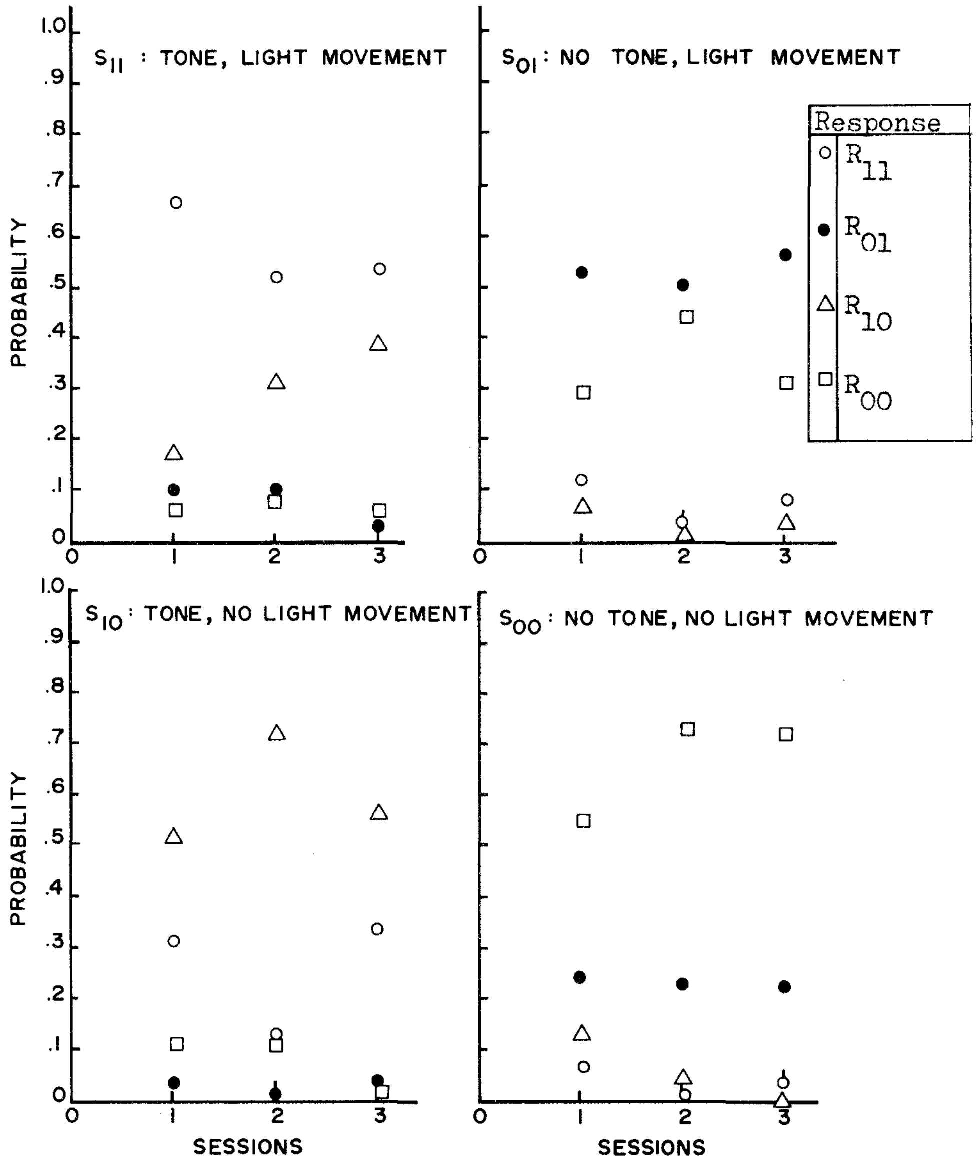
Conditional probabilities of the four responses, for each stimulus in Task 4. Subject 1



Conditional probabilities of the four responses, for each stimulus in Task 2. Subject 2



Conditional probabilities of the four responses, for each stimulus in Task 3. Subject 2



Conditional probabilities of the four responses, for each stimulus in Task 4. Subject 2

Appendix D

Instructions

This is one of a series of experiments on perceptual processes. There are three different tasks that will be asked of you, but on any one day, you will only be given instructions pertaining to the task for that day.

The room will be darkened during the experiment; on each trial, a light will flash in front of you. A short constant time later there will be a briefer flash. On a randomly selected one half of the trials, this latter flash will occur in the same position as the first, and on the other half, the light will move to the right by a constant amount.

During the entire experiment, you will hear noise through the earphones. On a randomly selected one half of the trials, there will be the noise plus a tone for the period between the two light flashes, and on the other half, the noise will remain the same, i.e., without the addition of a tone.

There are two possible lengths of time between the two flashes, two seconds or a half second. On each day, you will work on one of the three tasks at both interflash interval values. At the beginning of each session, you will be given one of the three sets of instructions; you will then be told which of the two interflash times will be presented first. There will be 48 practice trials followed by 200 trials, all having this time interval. The 200 trials will be divided into two blocks, 100 trials in each, between which you will have a one-minute rest period in the dark room. There will be no warning signal to denote the beginning of the second block; if you miss the first trial, do not worry but continue with the rest of the trials.

At the completion of the 200 trials, you will have a rest period of five minutes. Then 48 practice trials at the second time value will be presented, followed by 200 experimental trials, as before.

The light on which the light and/or sound changes are randomly and independently ordered for each block of 100 trials.

You will be seated in a chair which has 4 buttons on its right arm. Respond by pressing specific buttons; which ones will depend on the task that you are doing that day. The response must be made as soon as possible after the second flash of light. Once you have pressed a button, never change your mind and press another. A response must be made on every trial even if this means guessing.

Are there any questions?

Appendix E

Subject 1

Probability Matrices time: $t = 0.5$ sec.

Task 1

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	820	000	000	180	820	000	000	180	820	000	000	180
S_{01}	780	000	000	220	740	000	000	260	700	000	000	300
S_{10}	080	000	000	920	220	000	000	780	200	000	000	800
S_{00}	140	000	000	860	180	000	000	820	160	000	000	840
S_{11}	900	000	000	100	820	000	000	180	720	000	000	280
S_{01}	900	000	000	100	760	000	000	240	837	000	000	163
S_{10}	220	000	000	780	180	000	000	820	260	000	000	740
S_{00}	020	000	000	980	160	000	000	840	280	000	000	720

Task 3

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	449	184	265	102	220	260	360	160	500	220	220	060
S_{01}	160	600	060	180	220	460	120	200	224	531	082	163
S_{10}	120	020	550	280	102	061	392	245	060	000	700	240
S_{00}	060	080	380	480	060	100	400	440	040	180	280	500
S_{11}	500	220	280	000	620	280	100	000	600	220	120	060
S_{01}	245	531	122	102	245	490	143	122	220	420	220	140
S_{10}	060	040	720	180	082	082	633	204	082	041	612	265
S_{00}	041	041	347	571	082	122	306	490	000	060	300	640

Task 5

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	680	000	000	320	780	000	000	220	837	000	000	163
S_{01}	340	000	000	660	347	000	000	653	204	000	000	796
S_{10}	700	000	000	300	620	000	000	380	880	000	000	120
S_{00}	180	000	000	820	300	000	000	700	306	000	000	694
S_{11}	816	000	000	184	740	000	000	260	700	000	000	300
S_{01}	440	000	000	560	429	000	000	571	490	000	000	510
S_{10}	800	000	000	200	720	000	000	280	680	000	000	320
S_{00}	340	000	000	660	429	000	000	571	347	000	000	653

Subject 1

Probability Matrices time: t = 2 sec.

Task 1

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	612	000	000	388	408	000	000	592	551	000	000	449
S_{01}	480	000	000	520	540	000	000	460	500	000	000	500
S_{10}	360	000	000	640	300	000	000	700	400	000	000	600
S_{00}	360	000	000	640	280	000	000	720	380	000	000	620
S_{11}	562	000	000	437	600	000	000	400	633	000	000	367
S_{01}	620	000	000	380	600	000	000	400	480	000	000	520
S_{10}	440	000	000	560	340	000	000	660	400	000	000	600
S_{00}	540	000	000	460	400	000	000	600	520	000	000	480

Task 3

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	408	122	388	082	360	120	500	020	490	061	449	000
S_{01}	143	347	122	388	102	490	122	286	085	447	277	191
S_{10}	220	100	580	100	240	020	620	120	250	045	591	114
S_{00}	020	360	140	480	043	319	170	468	102	204	306	388
S_{11}	380	160	340	120	560	040	320	080	551	000	449	000
S_{01}	143	367	245	245	122	449	286	143	178	378	156	289
S_{10}	260	020	640	080	271	062	625	042	360	020	580	040
S_{00}	125	146	417	312	200	160	320	320	089	244	333	333

Task 5

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	860	000	000	140	875	000	000	125	760	000	000	240
S_{01}	180	000	000	820	167	000	000	833	320	000	000	680
S_{10}	900	000	000	100	816	000	000	184	680	000	000	320
S_{00}	100	000	000	900	184	000	000	776	360	000	000	640
S_{11}	918	000	000	082	940	000	000	040	940	000	000	060
S_{01}	300	000	000	700	320	000	000	680	260	000	000	740
S_{10}	940	000	000	060	898	000	000	082	940	000	000	060
S_{00}	240	000	000	760	388	000	000	612	180	000	000	820

Subject 2

Probability Matrices time: t = 0.5 sec.

Task 1

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	760	000	000	240	760	000	000	240	900	000	000	100
S_{01}	980	000	000	020	780	000	000	220	980	000	000	020
S_{10}	260	000	000	740	080	000	000	920	102	000	000	898
S_{00}	260	000	000	740	102	000	000	898	020	000	000	980
S_{11}	900	000	000	100	880	000	000	120	860	000	000	140
S_{01}	900	000	000	100	800	000	000	200	780	000	000	220
S_{10}	140	000	000	860	042	000	000	958	000	000	000	1.000
S_{00}	060	000	000	940	041	000	000	959	061	000	000	939

Task 3

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	460	380	060	100	240	480	120	160	280	420	160	140
S_{01}	280	480	120	120	160	480	080	280	200	560	000	240
S_{10}	080	100	300	520	040	000	460	500	060	020	520	400
S_{00}	020	100	340	540	060	080	220	640	020	000	280	700
S_{11}	200	400	140	260	367	367	143	122	265	102	327	306
S_{01}	100	600	100	200	180	540	020	260	080	560	120	240
S_{10}	020	122	267	490	040	000	400	560	020	000	440	540
S_{00}	040	060	140	760	020	020	160	800	000	020	200	780

Task 5

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	653	000	000	347	680	000	000	320	408	000	000	592
S_{01}	347	000	000	653	420	000	000	580	320	000	000	680
S_{10}	560	000	000	440	700	000	000	300	490	000	000	510
S_{00}	240	000	000	760	380	000	000	620	333	000	000	667
S_{11}	500	000	000	500	490	000	000	510	340	000	000	660
S_{01}	300	000	000	700	280	000	000	720	122	000	000	878
S_{10}	500	000	000	500	420	000	000	580	400	000	000	600
S_{00}	280	000	000	720	224	000	000	776	140	000	000	860

Subject 2

Probability Matrices time: t = 2 sec.

Task 1

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	580	000	000	420	520	000	000	480	520	000	000	480
S_{01}	633	000	000	367	400	000	000	600	640	000	000	360
S_{10}	480	000	000	520	320	000	000	680	460	000	000	540
S_{00}	250	000	000	750	280	000	000	720	250	000	000	750
S_{11}	540	000	000	460	720	000	000	280	460	000	000	540
S_{01}	520	000	000	480	640	000	000	360	320	000	000	680
S_{10}	360	000	000	640	280	000	000	720	240	000	000	760
S_{00}	280	000	000	720	280	000	000	720	240	000	000	760

Task 3

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	400	220	220	160	400	120	440	040	229	187	375	208
S_{01}	180	440	080	300	100	300	120	480	040	420	100	440
S_{10}	280	160	400	160	420	060	340	180	200	080	500	220
S_{00}	100	260	140	500	100	160	160	580	040	180	160	620
S_{11}	460	060	320	160	280	100	520	100	420	040	380	160
S_{01}	060	400	060	480	060	300	060	580	060	440	080	420
S_{10}	140	080	420	360	060	060	660	220	220	160	420	200
S_{00}	083	250	062	604	040	160	160	640	060	280	040	620

Task 5

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	780	000	000	220	860	000	000	140	755	000	000	245
S_{01}	122	000	000	878	160	000	000	840	224	000	000	776
S_{10}	740	000	000	260	720	000	000	280	604	000	000	396
S_{00}	120	000	000	880	040	000	000	960	265	000	000	735
S_{11}	720	000	000	280	720	000	000	280	720	000	000	280
S_{01}	160	000	000	840	140	000	000	860	100	000	000	900
S_{10}	740	000	000	260	735	000	000	265	700	000	000	300
S_{00}	120	000	000	880	080	000	000	920	220	000	000	780

Subject 3

Probability Matrices time: t = 0.5 sec.

Task 1

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	735	000	000	265	918	000	000	082	800	000	000	200	660	000	000	340
S_{01}	760	000	000	240	750	000	000	250	720	000	000	280	755	000	000	245
S_{10}	160	000	000	840	204	000	000	796	102	000	000	898	180	000	000	820
S_{00}	080	000	000	920	333	000	000	667	041	000	000	959	140	000	000	860

S_{11}	735	000	000	265	780	000	000	220	660	000	000	340
S_{01}	740	000	000	260	740	000	000	260	640	000	000	360
S_{10}	220	000	000	780	180	000	000	820	100	000	000	900
S_{00}	160	000	000	840	200	000	000	800	120	000	000	880

Task 3

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	542	167	187	104	383	170	277	170	408	347	082	163	400	340	060	200
S_{01}	300	460	080	160	457	239	196	109	347	286	122	245	300	420	040	240
S_{10}	122	041	429	408	217	043	457	283	040	040	420	500	082	061	429	429
S_{00}	060	040	420	480	128	064	362	447	109	065	283	543	041	122	306	531

S_{11}	400	300	200	100	540	240	120	100	408	327	143	122
S_{01}	180	420	060	340	200	500	060	240	240	460	140	160
S_{10}	060	060	520	360	100	080	460	360	020	040	580	360
S_{00}	060	140	240	560	020	180	220	580	041	061	245	653

Task 5

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	620	000	000	380	700	000	000	300	750	000	000	250	460	000	000	540
S_{01}	400	000	000	600	200	000	000	800	220	000	000	780	280	000	000	720
S_{10}	571	000	000	429	620	000	000	380	600	000	000	400	571	000	000	429
S_{00}	400	000	000	600	400	000	000	600	160	000	000	840	220	000	000	780

S_{11}	612	000	000	388	520	000	000	480	540	000	000	460
S_{01}	240	000	000	760	400	000	000	600	245	000	000	735
S_{10}	600	000	000	400	500	000	000	500	560	000	000	440
S_{00}	180	000	000	820	260	000	000	740	400	000	000	600

Subject 3

Probability Matrices time: t = 2 sec.

Task 1

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	490	000	000	510	440	000	000	560	660	000	000	340	360	000	000	640
S_{01}	580	000	000	420	420	000	000	580	640	000	000	360	540	000	000	460
S_{10}	327	000	000	673	260	000	000	740	400	000	000	600	360	000	000	640
S_{00}	449	000	000	551	396	000	000	604	260	000	000	740	360	000	000	640
S_{11}	460	000	000	540	420	000	000	580	520	000	000	480				
S_{01}	625	000	000	375	437	000	000	542	449	000	000	551				
S_{10}	260	000	000	740	286	000	000	714	300	000	000	700				
S_{00}	286	000	000	714	327	000	000	653	408	000	000	592				

Task 3

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	265	163	327	245	170	298	277	255	306	204	265	224	340	180	280	200
S_{01}	160	320	240	280	146	312	271	271	180	280	080	460	125	354	083	437
S_{10}	280	120	340	260	255	128	277	340	300	180	320	200	260	100	400	240
S_{00}	080	200	320	400	187	271	250	292	100	360	060	480	043	149	043	766
S_{11}	440	140	280	140	396	167	354	083	360	160	200	280				
S_{01}	102	388	061	449	184	306	143	367	000	521	000	479				
S_{10}	280	060	520	140	240	080	480	200	312	104	437	146				
S_{00}	082	286	122	510	080	280	100	540	000	280	040	680				

Task 5

	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}	R_{11}	R_{01}	R_{10}	R_{00}
S_{11}	581	000	000	469	694	000	000	306	755	000	000	245	800	000	000	200
S_{01}	240	000	000	760	080	000	000	920	060	000	000	940	102	000	000	898
S_{10}	600	000	000	400	776	000	000	224	700	000	000	300	720	000	000	280
S_{00}	265	000	000	735	234	000	000	766	102	000	000	898	100	000	000	900
S_{11}	840	000	000	160	900	000	000	100	920	000	000	080				
S_{01}	040	000	000	960	060	000	000	940	180	000	000	820				
S_{10}	920	000	000	080	880	000	000	120	755	000	000	245				
S_{00}	100	000	000	900	180	000	000	820	204	000	000	796				

Appendix F

Subject 1

X^2 values calculated to test whether responses on the visual problem are independent of responses on the auditory problem

Interlight Interval: t = 0.5 sec.

Session	1	2	3	4	5	6	Total over Stimulus (6df)
S_{11}	0.002	2.767	0.399	4.904*	2.160	0.168	10.400
S_{01}	0.103	0.148	0.047	1.824	1.768	3.386	7.276
S_{10}	0.957	0.256	0.970	1.049	2.110	0.036	5.378
S_{00}	0.007	0.293	1.208	0.182	0.006	1.368	3.064
Total over Stimuli (4df)	1.069	3.464	2.624	7.959	6.044	4.958	26.118 Total (24df)

Interlight Interval: t = 2 sec.

Session	1	2	3	4	5	6	Total over Stimulus (6df)
S_{11}	0.344	4.496*	2.409	0.064	2.020	0.000	9.333
S_{01}	0.151	1.091	9.252+	2.507	10.058*	0.036	23.095*
S_{10}	1.861	0.556	0.008	0.176	1.683	0.015	4.299
S_{00}	2.537	1.379	0.381	0.426	0.125	1.833	6.681
Total over Stimuli (4df)	4.893	7.522	12.050*	3.173	13.886*	1.884	43.408* Total (24df)

* -- significant at the 0.05 level

Subject 2

X^2 values calculated to test whether responses on the visual problem are independent of responses on the auditory problem

Interlight Interval: $t = 0.5$ sec.

Session	1	2	3	4	5	6	Total over Session (6df)
S_{11}	0.230	1.933	1.434	3.403	0.764	3.402	11.166
S_{01}	0.357	0.175	0.964	0.031	0.523	0.166	2.216
S_{10}	0.374	3.444	0.020	0.302	1.577	0.532	6.249
S_{00}	0.234	1.380	0.029	2.189	0.000	1.673	5.505
Total over Stimuli (4df)	1.195	6.932	2.447	5.925	2.864	5.773	25.136 Total (24df)

Interlight Interval: $t = 2$ sec.

Session	1	2	3	4	5	6	Total over Session (6df)
S_{11}	0.859	0.431	0.757	0.015	0.067	1.925	4.054
S_{01}	0.658	0.044	3.947*	2.380	2.009	2.925	11.963
S_{10}	0.216	2.084	0.544	2.031	2.546	1.020	8.441
S_{00}	1.176	0.815	2.380	1.819	1.176	0.255	7.621
Total over Stimuli (4df)	2.909	3.374	7.628	6.245	5.798	6.125	32.079 Total (24df)

* significant at the 0.05 level

Subject 3

X^2 values calculated to test whether responses on the visual problem are independent of responses on the auditory problem

Interlight Interval: t = 0.5 sec.

Session	1	2	3	4	5	6	7	Total over Sessions (7df)
S_{11}	0.735	0.310	1.594	3.765	0.397	0.882	0.017	7.700
S_{01}	0.167	0.004	2.032	3.457	1.480	0.391	0.683	8.214
S_{10}	1.545	1.855	0.044	0.106	0.195	0.000	0.058	3.803
S_{00}	0.320	1.409	2.300	0.421	0.000	1.342	0.397	6.189
Total over Stimuli (4df)	2.767	3.578	5.970	7.749	2.072	2.615	1.155	25.906 Total (28df)

Interlight Interval: t = 2 sec.

Session	1	2	3	4	5	6	7	Total over Sessions (7df)
S_{11}	0.125	1.121	0.164	0.275	0.492	0.651	3.760	6.588
S_{01}	0.855	1.680	3.265	0.729	0.723	0.536	0.000	7.788
S_{10}	0.906	2.084	0.004	0.468	0.089	0.114	0.000	3.665
S_{00}	1.059	0.124	1.012	2.467	0.048	0.377	0.898	5.985
Total over Stimuli (4df)	2.945	5.009	4.445	3.939	1.352	1.678	4.658	24.026 Total (28df)