SIGNAL DETECTION AS A FUNCTION OF REDUNDANT AUDIO-VISUAL PRESENTATION

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SUMMARY

The number of studies on redundant bisensory detection has been few, and those comparing unimodal with bimodal detection rates are fewer still. The present study went beyond a mere comparison of unimodal and bimodal presentations with the same detection rates for each modality by looking at the detection rates for unimodal and bimodal presentations of various intensities. Three different intensities of auditory signals and three different intensities of visual signals were used. The bimodal presentations incorporated the nine possible combinations of these intensities. The results supported the hypotheses that bimodal detection rates were in general higher than unimodal detection rates, and that there were significant differences when some intensities of bimodal presentations were compared with each other. A mathematical model assuming independent detection probabilities for a visual signal and an auditory signal, used by Osborn et al. (1963) to predict detection rates under bisensory presentation, did not predict the results in the present study.

CHAPTER I

INTRODUCTION

With a multitude of tasks becoming increasingly complex and with sensory information reaching the limit of human capabilities for processing over the auditory and visual modalities, attempts have been made to use other sensory channels or to use more than one sensory channel for the same information. The first of these has dealt primarily with the tactual senses (Geldard, 1957), and although it has been shown that information can be processed using this modality, few if any practical tactual communication systems have been developed. (McCormick, 1964, p. 177).

The possibility of using more than one sensory modality is now receiving increasing interest, especially in the areas of detection and vigilance. Detection and vigilance are important not only in controlling air traffic and in the defense of the nation, but in industrial jobs such as the scanning of assembly-line products for defects (Adams, 1956).

Detection is concerned with answering the question, "Is there anything there?" Vigilance is concerned with the detection of signals over prolonged periods of time. In vigilance tasks, signals frequently occur irregularly in time and are few in number. Vigilance is also particularly concerned with the decrement in detection performance over time. Although the present experiment was strictly a detection task, similar results occurred in experiments with vigilance tasks which involved bi-sensory presentations (Buckner and McGrath, 1963; Baker et al., 1962; Osborn et al., 1963). In addition, many of the studies cited deal with the detection of just noticeable differences rather than detection of the presence or absence of a signal. Some studies provide knowledge of results (feedback), and others do not. Table 1 provides a summary of the techniques used in each experiment, including the present one. Many of these studies are mentioned by Brebner (1963).

Loveless (1957) compared detection rates using uni-sensory and bisensory displays. The signals consisted of momentary increments in the intensity of background noise. Subjects were asked to indicate whether a signal was present or absent following a ready signal, and knowledge of results was given. Signals were presented on only 50 per cent of the possible occasions, the sequence of signals and no-signals being randomly determined. Of the 15 half-hour sessions given to each subject, one form of presentation (auditory, visual, or bisensory) and one form of five signal-to-noise ratios was used each session. "The bisensory presentation yielded a detection rate consistently higher than that obtained with the better uni-sensory display."

Later, Loveless (1959) ran an experiment to find out whether seeing and hearing were less efficient in terms of differential sensitivity when the operator had to attend to both channels simultaneously than when he had to attend to only one. Three groups were run. Groups I and II used the single auditory and visual presentations respectively. Group III was required to decide which of four possible events had occurred--

Table 1. Summary of Techniques Used in Each of the Experiments Cited

Experimenter	Type of Task	Length of Observation	No.of Trials	Type of Signal	Feed-back
Loveless (1957)	Detection	15 Half-Hour Sessions	120/ Session	Just notice-able difference (jnd)	Yes
Loveless (1959)	Detection	30 Minutes	120	jnd	Yes
Buckner & McGrath (1963)	Vigilance	15 One-Hour Watches	24/ Watch	jnd	No
Baker et al. (1962)	Vigilance	3 Hours	36 and 72	Interruptions of continuous sound or light	No
Osborn et al. (1963)	Vigilance	3 Hours	72	Interruptions of continuous sound or light	No
Brown & Hopkins (1967)	Detection	10 200 sec. tests	50/ Test	Pure tone or oscilloscope trace	Yes
Jorgeson (1967)	Detection	1 Hour	1,040	Pure tone or projector light	No

an auditory signal, a visual signal, a double signal, or a blank signal. Each event took place 30 times. Knowledge or results was provided to the observers. Results showed that "seeing and hearing were just as efficient when subjects were forced to attend to both channels as when they attended to one only."

Buckner and McGrath (1963) found the number of detections in a vigilance task to be greater when the signals were presented over two modalities as compared with either the auditory modality or the visual modality alone. Differential rather than absolute sensitivity was studied in 15 one-hour watches.

In the experiments by Baker, Ware, and Sipowicz (1962) and by Osborn, Sheldon, and Baker (1963), observers were required to detect brief interruptions (.03 seconds and .041 seconds respectively) of a continuous sound or light. The watch periods lasted for three hours and signals were presented on a random intersignal interval schedule. In the first study, one group, the redundant signal group, received 72 combined audio-visual signals; a second group received 72 visual signals, and a third 72 auditory signals; a fourth group, the nonredundant group, received 72 signals--36 auditory and 36 visual--separated in time so that no two signals from different sensory modes occurred at the same time; the fifth and sixth groups received 36 visual and 36 auditory signals respectively. "Although the per cent of signals detected was higher for the redundant group (Group 1), the difference between the redundant group and the two auditory control groups (Groups 3 and 6) was not statistically significant." Osborn found significant differences between a redundant group, a nonredundant auditory group, and a nonredundant visual group. Except for an initial drop in the auditory curve, the two components of the redundant signal approximated the corresponding nonredundant auditory and visual functions. Osborn suggests that we can assume independent detection probabilities for a visual signal (Pv) and an auditory signal (Pa). An estimate of the combined detectability, i.e., the detection of both signals when they are presented simultaneously to both modalities, is given in their joint probability, PaPv = Pav. The probability of a redundant detection is Pa + Pv - Pav. The theoretical and observed values in Osborn's study were very close although the theoretical values were in general somewhat higher than the observed values. The results confirmed and strengthened a summation hypothesis for redundant information.

In a very recent study, Brown and Hopkins (1967) note that "a noticeable enhancement in performance occurs when the observers are given redundant information in the form of simultaneous auditory and visual signals." In agreement with the mathematical model derived from information processing and signal detection theory used to predict experimental data (Osborn et al., 1963), their results imply that "each sensory modality performs in an independent manner, and that the improved detection results from simple probabilistic adding."

Present Study

In the present experiment high, medium, and low rates of detection of auditory signals and of visual signals were determined individually for each subject using a randomly-mixed two-staircase series of presentations for threshold determination. This is more thoroughly discussed under PROCEDURE. The subjects were then given a random presentation of these signals or combinations of these signals to detect. Each signal could be an auditory signal, a visual signal, or both an auditory signal and a visual signal presented simultaneously. In several randomly determined instances, no signal was presented to make sure the subject was not faking responses. All possible combinations of the three intensities of auditory and visual signals were presented during the simultaneous, bimodal presentations. Since each subject was run under each condition, there was no problem of the possibility of group differences which would have occurred if a group had been assigned to each condition. Because a variety of rates of detection or intensities of the signals were used, it was possible to look at the effect upon detection of combining various intensities of one modality with various intensities of another modality. In addition, it was possible to make bimodal comparisons. The independent variables studied, therefore, were the modalities of presentation (no modality, audio, visual, and audio-visual) and the probabilities of detection for each modality alone (the three different intensities). The dependent variable was the number of signals detected under each of the independent variables.

The hypotheses to be tested in the present experiment were:

1. The number of signals detected at each of the three different intensities, for any one modality, will be significantly different from each other.

2. If a signal from one modality is supplemented by the simultaneous presentation of a signal from another modality, the number of detections will be greater for the two modalities than for either original modality alone.

3. The number of detections under some bimodal conditions should be significantly better than for some other bimodal conditions.

4. The observed values of detection under bimodal presentation should be close to those predicted by the model Pa + Pv - Pav.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

The visual stimulus was a one-half inch square of light. The light was produced by a Polymetric Tachisto-Projector, Model V-1459-3, with the light projected onto the back of several thicknesses of white paper. Kodak Neutral Density Wratten Gelatin Filters, No. 96, were inserted into each of the three projectors of the tachisto-projector to control intensities. Intensities were varied in a step-wise fashion by the experimenter. The auditory signal was a 1000 cps pure tone produced by a General Radio Unit R-C Oscillator, Type No. 1210-C, with a General Radio Unit Power Supply, Type 1203-B. The audio signals were presented in a step-wise fashion by the experimenter over Brush Crystal Headphones, Model BA-206, to both ears. The three audio intensities were controlled by three pairs of Mallory 3000 ohm T-Pad Attenuators, Model T-3000. The set-up permitted the manual presentation of any of the three auditory channels or any of the three visual channels. For the actual experiment the presentation of signals was controlled by a Grason-Stadler Stepper, Model E3129C. The stepper was a 12-pole, 26-position stepping switch. The stepper and subject response light were powered by a Scientific Prototype Regulated Power Supply which supplied a 10 amp 26VDC current. The stepper was pulsed each second by a Hunter Interval Cycler, Model 124S. Since more than 26 positions were needed and two poles were sufficient, the stepper was wired so that, if the correct pair of switches were switched on the stepper control panel after every 26th pulse, the stepper acted as a two-pole, 156-position stepping switch. A block diagram of the apparatus appears in Figure 1 of the Appendix.

CHAPTER III

PROCEDURE

Eleven male students of an undergraduate introductory psychology course at Georgia Institute of Technology served as subjects in the experiment. They were all volunteers but received some credit toward their final grade in the course for their three hours of participation. Each subject was run individually on two successive days. Subjects had no known auditory or non-corrected visual problems. If the subject was wearing a watch, it was removed for the duration of the experiment each day. Subjects were told that the experiment was concerned with their individual ability to detect auditory and visual signals. They were instructed to press the telegraph key in front of them whenever they detected a signal. The key press turned on a light in the experimenter's booth, and the response was recorded. Before the session began, subjects were introduced to the signal at an easily detectable intensity. They were instructed that the signals would occur irregularly in time and that there was no pattern of signals that could be memorized. To give meaning to the experiment and to motivate the subjects, they were told that the task could be thought of as simulating a vital pilot task.

Due to the 120VAC equipment used, a 60-cycle hum was present during most of the experiment, and could not be eliminated from the headphones. The subjects were informed that they would probably hear the

60-cycle hum most of the time and that whenever a signal might be presented, the hum would go off and a click might be heard simultaneously with the onset and offset of the signal. This did not mean that a signal of detectable intensity occurred every time the hum went off, and no subject responded in this manner. The room lights were then turned off so that the subject's eyes could become dark adapted during the auditory presentations. Approximately 160 judgments were made to the auditory signals by using a randomly mixed two-staircase series of presentations for threshold determination. This method is described by Cornsweet (1957) and essentially involves a random switching of two staircase series. For example, if the signal in the next staircase was detected last time, the signal is reduced in intensity by a fixed amount, and if the signal was not detected last time, it is increased in intensity by a fixed amount. This method was selected because many judgments are wasted in the method of limits in determining the threshold. In the method of limits only the point at which the subject changes his response is important, and all responses up to that point are not used. The randomly mixed two-staircase method provided a much more efficient method.

After the auditory presentations, which took approximately half an hour, subjects removed their headphones, and the visual stimuli were presented using the same method. Data from the first day were used to determine intensities for a high, medium, and low rate of detection for each subject. Ideally, 75 per cent, 50 per cent, and 25 per cent detection rates per total number of signals presented at each intensity were desired. However, this was not always achieved, as will be discussed later.

On the second day, subjects were given a brief auditory test again by the method of constant stimuli so that any day-to-day changes could be corrected. Subjects were then told that they were to press the telegraph key whenever they detected an auditory signal, a visual signal, or both an auditory signal and a visual signal presented simultaneously. They were also informed that the clicks would now occur every second (caused by the interval cycler pulsing the stepper) and that signals, when they occurred, would last for one second. Again, there was no pattern of signals that could be memorized.

To be sure that subjects could detect both auditory and visual signals and the combination of the two when the stepper was used to present the signals, and to give them practice, approximately ten minutes of practice were given and final adjustments of intensities were made. Subjects were then instructed that the experiment would last approximately one hour without a break. During this time 1,040 judgments were made by each subject. Since a signal was initiated every three seconds, to make sure that subjects were not pressing the key every three seconds when the hum went off, 140 of the judgments involved the absence of a signal, that is, there was silence. These were called "catch" trials and indicated the false alarm rate. Sixty judgments were made by each subject under each of the 15 remaining conditions (three rates of auditory detection, three rates of visual detection, and 3x3 rates of auditory-visual detection). Three randomly selected orders of the 15 different conditions, plus two or three catch trials, were used in succession for the 1,040 presentations.

CHAPTER IV

RESULTS

For almost every subject both auditory and visual intensities had to be increased on the second day despite the fact that thresholds were determined individually for each subject. The large number of judgments to determine the thresholds on the first day seemed to serve only as a rough guide to the thresholds of the second day. Although an earnest effort was made to equate subjects by determining individual thresholds, wide individual differences in detection rates occurred. Some subjects detected more than twice as many signals as other subjects.

Initially high, medium, and low rates of detection for auditory signals and for visual signals were desired. These were to correspond to approximately 75 per cent, 50 per cent, and 25 per cent detection rates. The average number of detections for all subjects under the visual condition were fairly close to these with the detection rates being 74 per cent, 60 per cent, and 28 per cent respectively. However, individual detection rates varied tremendously from 22 to 93 per cent under the high intensity, 15 to 90 per cent under the medium intensity, and zero to 83 per cent under the low intensity.

Under the auditory condition, detection rates were less than expected. For the three intensities the average detection rates for all the subjects were 37 per cent, 30 per cent, and 20 per cent. Again, individual differences were great. The low rates of auditory detection can probably be explained by the presence of undesirable static in the headphones which could not be eliminated and which occurred when auditory signals should have been present. It was therefore decided to label the visual detection rates high, medium, and low, and the auditory detection rates medium-low, low, and very low. The abbreviations for these rates and for the audio-visual combinations are shown in Table 2.

Table 2. Abbreviations for the Audio, Visual, and Audio-Visual Detection Rates, and the Average Per Cent of Signals Detected by Subjects Under Each Condition

	VISUAL			
AUDIO	Absent	High	Medium	Low
Absent		V_h	V_m	V_l
Very Low	A_{vl}	$A_{vl}V_h$	$A_{vl}V_m$	$A_{vl}V_l$
Low	A_l	A_lV_h	A_lV_m	A_lV_l
Medium-Low	A_{ml}	$A_{ml}V_h$	$A_{ml}V_m$	$A_{ml}V_l$

Because the data gave evidence of not being normally distributed, because of lack of homogeneity of variance, and because the number of subjects was small, the data were analyzed by use of a nonparametric "distribution-free" test, the Wilcoxon matched-pairs signed-ranks test (Moses, 1952, and Siegel, 1956). The Wilcoxon test was selected as the most suitable nonparametric test because it was easy to use and provided a reasonable level of measurement using ordinal data. If statistical differences are found using a nonparametric test, the differences would be even more significant using a parametric test since a parametric test has more power (Ferguson, 1966).

In many cases the direction of the differences could be predicted in advance, and a one-tailed test was used. However, in other cases the direction could not be predicted and a two-tailed test was used. The number of false alarms, that is, the number of responses to trials where no signals were present, was negligible (eight out of 1,540 possibilities). The null hypothesis, Ho, was that there was no difference between the sum of the positive ranks and the sum or the negative ranks; that is, that there was no difference between the number of detections under each of the two conditions being compared at a time. The results of those tests are shown in Table 3, which shows all possible paired comparisons of the 15 presentations. An asterisk indicates that the column intensity is significantly greater than the row intensity at the .01 level of significance. In one instance ($V_m > A_{ml}$) the column intensity was significantly greater than the row intensity at the .025 level. A stronger test, the randomization test for matched pairs (Siegel, 1956), was consequently applied to this case. The difference was found to be significant at the .01 level of significance.

Each of the following nine paragraphs has a number preceding it. Any cell in Table 3 which is relevant to any of the nine paragraphs has a number or numbers in the upper left-hand corner corresponding to the paragraph or paragraphs to which it is relevant. A "2" in bottom right-

Table 3. The Relationship of Presentations to Each Other

NOTES: An asterisk (*) indicates that the column value is greater than the row value at the .01 level of significance. A dash (-) indicates no significant difference. The number or numbers in the upper left-hand corners refer to the paragraphs in the text. A one-tailed test was run in all cells containing an asterisk or dash except where a "2" appears in the bottom right-hand corner. This indicates that a two-tailed test was run.

	A_{vl}	A_l	A_{ml}	V_l	V_m	V_h	$A_{vl}V_h$	$A_{vl}V_m$	$A_{vl}V_l$	A_lV_h	A_lV_m	A_lV_l	$A_{ml}V_h$	$A_{ml}V_m$	$A_{ml}V_l$
A_{vl}		3 *	3 *	5 - 2	5 *	5 *	1 6 *	1 6 *	1 6 *	6 *	6 *	6 *	6 *	6 *	6 *
A_l			3 -	5 - 2	5 *	5 *	6 *	6 *	6 - 2	1 6 *	1 6 *	1 6 *	6 *	6 *	6 *
A_{ml}				5 - 2	5 *	5 *	6 *	6 *	6 - 2	6 *	6 *	6 *	1 6 *	1 6 *	1 6 -
V_l	5 - 2	5 - 2	5 - 2		4 *	4 *	6 *	6 *	2 6 *	6 *	6 *	2 6 *	6 *	6 *	2 6 *
V_m						4 *	6 *	2 6 *	6 - 2	6 *	2 6 *	6 - 2	6 *	2 6 *	6 - 2
V_h							2 6 *	6 - 2	6 - 2	2 6 *	6 - 2	6 - 2	2 6 *	6 - 2	6 - 2
$A_{vl}V_h$										8 -			8 -	8 - 2	
$A_{vl}V_m$						6 - 2	8 *			8 *	8 -	8 - 2	8 *	8 -	8 - 2
$A_{vl}V_l$		6 - 2	6 - 2		6 - 2	9 * 2	7 *	7 *		7 *	7 *	7 *	7 *	7 *	7 -
A_lV_h													8 -	8 -	
A_lV_m						6 - 2	8 -			8 -			8 -	8 -	
A_lV_l					6 - 2	6 - 2	7 *	7 - 2		7 *	7 *		7 *	7 *	7 -
$A_{ml}V_h$															
$A_{ml}V_m$						6 - 2	8 - 2			8 - 2			8 -		
$A_{ml}V_l$					6 - 2	6 - 2	7 *	7 * 2		7 *	7 *		7 *	7 *	

hand corner of a cell indicates that a two-tailed test was run. Otherwise a one-tailed test was run.

1. Supplementing any of the auditory signals with simultaneously presented visual signals at any of the intensities under consideration lead to a significant increase in detection rate in all cases except where A_{ml} was compared with $A_{ml}V_l$.

2. Supplementing any of the visual signals with simultaneously presented auditory signals at any of the intensities under consideration lead to a significant increase in detections in all cases.

3. A_l and A_{ml} were significantly better than A_{vl}, but A_{ml} was not significantly better than A_l.

4. V_h was significantly better than V_m and V_l, and V_m was significantly better than V_l.

5. Except for the low rate of visual detection, V_l, the detection rate was significantly better for the visual modality than for the auditory modality.

6. Whenever two modalities were presented simultaneously, and V_h or V_m was one of the two modalities, the detection rate for the two modalities was significantly better than for any one modality, the only exception being that V_h was not significantly different from $A_{\_}V_m$. Whenever two modalities were presented simultaneously and V_l was one of the two modalities, the bimodal presentation may or may not have been significantly greater than one modality depending upon the intensity of the auditory signal paired with V_l and the intensity and modality of the single modality.

7. When bimodal presentations were compared with each other, fewer significant differences were found than when one modality was compared with two modalities. The easiest way to state the results was that whenever V_l was part of one bimodal presentation, any other bimodal presentation containing V_m or V_h was significantly better except that $A_{vl}V_m$ was not significantly better than A_lV_l. Whenever V_l was part of both bimodal presentations, there was no significant difference between the two modalities except that A_lV_l was significantly greater than $A_{vl}V_l$.

8. $A_{-}V_h$ was significantly better than $A_{vl}V_m$. Other than this exception no bimodal presentation was significantly better than any $A_{-}V_m$ or $A_{-}V_l$ presentation.

9. V_h was significantly better than $A_{vl}V_l$ at the .01 level.

Table 4 shows the average predicted and obtained detection rates for all subjects under the bimodal condition and the obtained rates under the unimodal condition. The predicted value comes from the formula Pa + Pv - Pav suggested by Osborn (1963). Using the nonparametric Friedman two-way analysis of variance by ranks for k correlated samples (Ferguson, 1966), the predicted and obtained detection rates were significant at the .05 level. The Friedman test was used because a nonparametric test was required and there were k related samples. The Friedman test also uses the higher level of measurement available, the ordinal scale. The obtained value was usually somewhat greater than the predicted value.

Table 4. A Comparison of Predicted and Obtained Detection Rates Under the Bimodal Condition Given the Obtained Values Under the Unimodal Condition

Condition	Obtained Value	Predicted Value
A_{vl}	20%	
A_l	30%	
A_{ml}	37%	
V_l	28%	
V_m	60%	
V_h	74%	
$A_{vl}V_h$	84%	79%
$A_{vl}V_m$	73%	68%
$A_{vl}V_l$	46%	42%
A_lV_h	86%	82%
A_lV_m	78%	72%
A_lV_l	60%	49%
$A_{ml}V_h$	87%	84%
$A_{ml}V_m$	81%	75%
$A_{ml}V_l$	53%	55%

Predicted Value = Pa + Pv - Pav. The predicted value of 79% for $A_{vl}V_h$ was obtained by adding the average detection rate for A_{vl}, 20%, and the average detection rate for V_h, 74%, and then subtracting the product, 15%.

CHAPTER V

CONCLUSIONS

For the intensities studied in this experiment, the following general conclusions can be drawn.

The hypothesis that the number of signals detected at each of three different intensities for any one modality will differ significantly from each other is confirmed in all cases but one. (Numbers 3 and 4 in RESULTS.)

The hypothesis that supplementing a signal of one modality with the simultaneous presentation of a signal of another modality will lead to an increase in the number of signals detected is confirmed in all cases but one. (Numbers 1 and 2 in RESULTS.)

The hypothesis that there will be significant differences among some bimodal conditions is also supported. Whenever V_l was part of a bimodal presentation, any bimodal presentation containing V_m or V_h was significantly better except that $A_{vl}V_m$ was not significantly better than A_lV_l. $A_{-}V_h$ was significantly better than $A_{vl}V_m$, and A_lV_l was significantly better than $A_{vl}V_l$ at the .01 level. (Numbers 7-8 in RESULTS.)

The hypothesis that the equation Pa + Pv - Pav would predict the bimodal detection rates was not confirmed. Contrary to the results of Osborn where the predicted values were greater than the obtained values, in eight of the nine cases in the present study the obtained values were greater than the predicted values by approximately 5 per cent.

In conclusion, it can be stated that if the opportunity is presented of using two modalities rather than one modality to detect near threshold signals, the opportunity should be taken unless there is evidence that this interferes with other sensory, information processing, or motor tasks. Such interference might occur, for example, if the auditory channel were already loaded to capacity and an additional task were placed upon it, or if the use of an additional channel restrained the receiver's requirements of movement.

APPENDIX

Table 5. Number of Signals Detected, Out of a Possible 60 Per Cell by Each Subject Under Each Condition

SUBJECT	A_{vl}	A_{l}	A_{ml}	V_{l}	V_{m}	V_{h}	A_{vl} V_{h}	A_{vl} V_{m}	A_{vl} V_{l}	A_{l} V_{h}	A_{l} V_{m}	A_{l} V_{l}	A_{ml} V_{h}	A_{ml} V_{m}	A_{ml} V_{l}	Total	False Alarms
1	35	44	40	26	50	41	59	54	55	53	58	56	58	58	49	736	1
2	22	27	31	15	35	53	57	49	36	58	51	45	55	51	42	627	0
3	11	8	18	31	54	56	58	57	52	59	57	52	60	59	50	682	0
4	1	21	17	0	33	34	34	26	2	35	48	20	39	44	8	362	0
5	6	15	28	0	8	13	40	23	12	40	22	25	47	41	19	339	0
6	6	9	20	2	23	40	48	40	4	46	48	15	44	36	15	396	1
7	13	21	20	50	54	55	58	58	54	55	58	55	55	59	53	718	0
8	6	15	18	16	35	50	52	37	20	59	45	37	55	53	27	525	0
9	19	19	25	34	45	54	58	51	41	58	55	51	58	51	49	668	2
10	10	14	15	7	37	50	53	51	11	54	43	27	53	49	16	490	4
11	3	8	10	3	21	40	39	32	14	47	31	15	52	31	24	370	0
Total	132	201	242	184	395	486	556	478	301	564	516	398	576	532	352	5,913	8
Per Cent	20	30	37	28	60	74	84	73	46	86	78	60	87	81	53		

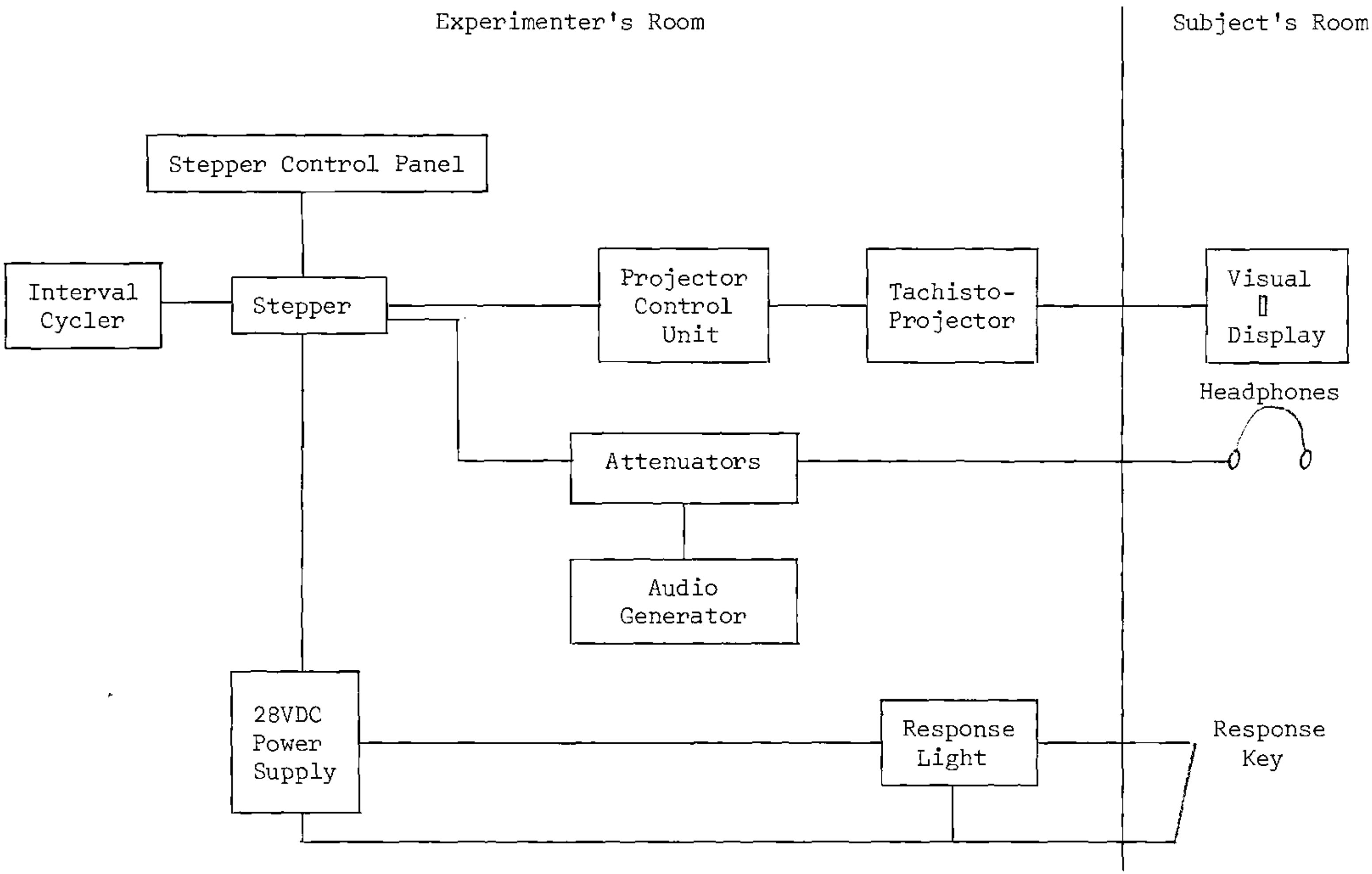

Figure 1. Apparatus

A_{vl}	35	22	11	1	6	6	13	6	19	10	3
V_h	41	53	56	34	13	40	55	50	54	50	40
d	-6	-31	-45	-33	-7	-34	-42	-44	-35	-40	-37
Rank	-1	-3	-11	-4	-2	-5	-9	-10	-6	-8	-7

The sum of negative ranks is 66.
The sum of positive ranks is zero.
The smaller of the two sums, therefore, is zero.
N = 11 in this example, and according to the table, a value equal to or less than seven is required for significance at the 1 per cent level for a one-tailed test. Since the smaller value is zero, and this is less than seven, we can reject the null hypothesis that the sum of the positive ranks will tend to equal the sum of the negative ranks and concludes that the number of detection for V_h is significantly better than for A_{vl}.
Each pair of tied observations reduces the value of N by one, and when d's of equal value occur, the average rank is taken.

Figure 2. The Wilcoxon Matched-Pairs Signed-Ranks Test for Two Correlated Samples

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