THE INFLUENCE OF VISUAL TEXTURE ON THE VISUAL FACILITATION OF AUDITORY LOCALIZATION

GEORGE RAYMOND MASTROIANNI

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THE INFLUENCE OF VISUAL TEXTURE ON THE VISUAL FACILITATION OF AUDITORY LOCALIZATION

BY

GEORGE R. MASTROIANNI

B.S. (Psychology), Georgetown University, 1977
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A DISSERTATION

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ABSTRACT

THE INFLUENCE OF VISUAL TEXTURE ON THE VISUAL FACILITATION OF AUDITORY LOCALIZATION

by

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University of New Hampshire
May, 1981

A substantial but contradictory literature on intersensory effects exists. Studies have been reported showing facilitation of sensitivity in one modality when other modalities are stimulated, as have studies showing inhibition of sensitivity in one modality when other modalities are stimulated. Studies reporting no effects whatever of multimodal stimulation have also been reported. This literature is reviewed in detail.

A recent series of experiments by Warren and his colleagues report a facilitating effect of simultaneous visual facilitation on the variability of responding in an auditory localization task. They hypothesize that the presence of visual texture in the light in conjunction with eye movements makes possible a more precise visual, and hence auditory, localization.
A series of nine experiments was conducted. In one experiment, auditory frequency discrimination was tested under three levels of illumination: light with texture, dark, and light without texture. No differences across illumination conditions were observed. The other eight experiments were designed to test for the necessity of visual texture in the visual facilitation of auditory localization by comparing performance in the light with texture condition to that in the light without texture condition. A variety of methods to measure localization was used, including the method of constant stimuli, pointing with a rigid rod, pointing with the arm and hand, and a signal detection paradigm. Stimulus characteristics were also varied: pure tones and clicks were both used as the stimuli to be localized.

While two statistically significant findings of facilitation occurred, the bulk of the evidence led to the conclusion that the facilitation of auditory localization was not demonstrated in this series of experiments.

These results were discussed in terms of common explanations of intersensory effects. The possibility that the alerting or activating function of accessory stimulation could be the basis for the effect was raised. It was hypothesized that habituation of the alerting response might
be responsible for the inconsistent pattern of results found in the literature. Suggestions for future research were noted.
INTRODUCTION AND REVIEW OF LITERATURE

It has been thought since at least 1669 that auditory sensitivity is higher in a lighted environment than in a dark one (Hartmann, 1934). A revival of interest in this phenomenon occurred in the early part of this century coincident with the rise of Gestalt psychology. The Gestaltist notion that "some functional unity characterizes the entire senscrium" (Hartmann, 1934) stimulated considerable research on the interrelation of the sensory modalities. Research of this kind has been conducted more or less continuously since the heyday of Gestalt, but recent years have brought an increasing interest in the topic.

Hartmann, a Gestalt psychologist, performed an experiment in 1934 that was designed to assess the effects of visual stimulation upon simultaneously occurring auditory functions. This study was an extension of his earlier research, which had shown an increase in visual acuity coincident with the stimulation of other major sense organs (Hartmann, 1933a, 1933b). Hartmann's hypothesis was that a reciprocal interchange of energy among various train centers was responsible for these results. The 1934 study was intended to test this hypothesis by testing the reciprocity
of the relation between vision and audition. Hartmann's method was quite straightforward. Using responses to the Seashore Test of Musical Talent as a dependent measure, Hartmann compared subjects' auditory pitch and intensity discrimination under light conditions to their performance in the dark. While Hartmann reported a facilitative effect of illumination on auditory function, his findings were not simple and clear-cut. In one condition of his study, for example, he found that an alteration of the response required of the subject actually led to an increase in auditory sensitivity in the dark.

In one condition, the subject was required to write down his/her responses to the Seashore record. A small 10-watt bulb was provided for this purpose. In an effort to remove this small amount of light and more adequately contrast light with dark, Hartmann required his subjects to make a verbal response, extinguished the light, and recorded the responses himself. He found an increase in auditory sensitivity in the light in the former procedure, but observed an increase in auditory sensitivity of a similar magnitude in the dark in the latter procedure. Many of the more complex intersensory findings were disputed by Kravkov (1934). Burnham (1941) reanalyzed Hartmann's data and found little reason for confidence in most of the effects reported. By subjecting Hartmann's data to slightly more rigorous statistical analysis, Burnham concluded that Hartmann's effects were probably not significant.
The equivocal nature of the experimental evidence for the effect is not restricted to Hartmann's research. Indeed, it predates it. Heymans (1904) and Jacobsen (1911) both reported on the inhibitory effects of the simultaneous stimulation of one sensory modality on the other. The inhibitory effect of sound stimulation or pressure sensitivity, and of inattention on sensitivity in both modalities were measured by Jacobsen. He concluded that voluntary concentration could overcome the inhibitory effect of accessory stimulation. Urbantschitsch (1888), in a long series of experiments, had previously reported a wide range of facilitating intermodal effects. Gilbert (1941), in a review of the literature on this topic, remarked on Urbantschitsch's crude methods but prodigious efforts and gave him credit primarily for bringing the facilitation phenomenon to the attention of other investigators. Ide (1919) also found facilitating effects of auxiliary stimulation. He tested weight-lifting and found that a hot or cold weight felt heavier than comparison weights at room temperature.

As there was controversy before Hartmann and Kravkov, so there was afterward. A number of studies reporting positive facilitating intermodal effects have appeared in the literature since then, as have a number of studies reporting negative results, as well as some reporting inhibitory intermodal effects. A few examples may serve to illustrate the nature of the evidence for this phenomenon.
In two studies (Child and Wendt, 1936; Child and Wendt, 1938) the temporal course of the visual facilitation of auditory sensitivity was traced, leading to the conclusion that visual stimulation presented within one-half second prior to an auditory stimulus increased auditory sensitivity to the stimulus, but had no effect on sensitivity if the visual stimulus was presented either two seconds before or one-half second after the auditory stimulus. Child and Wendt (1938) admitted that the effects were of small magnitude. Cason (1936) on the other hand, found that subjects' rating of the magnitude of both visual and auditory stimuli was increased when either was presented with the other; however, this effect was small to begin with and disappeared or reversed with repeated presentation of the stimuli. Gregg and Brogden (1952) found in pilot work that simultaneous light or sound stimulation could each have either an inhibitory or a facilitating effect on the other modality. Their hypothesis to explain this was that instructions to the subject were responsible for this variability in the effects of accessory stimulation. When the subject was instructed to report on the presence of the auxiliary stimulus, they predicted a decrease in sensitivity in the tested modality. When subjects were instructed to report only stimuli in the tested modality, they expected an increase in sensitivity. These hypotheses were confirmed by the results of their experiment. Thompson, Voss and Brogden (1958) attempted to extend these findings by testing
auditory detection thresholds at 9 levels of illumination. Four of the illumination levels were subthreshold, one was at threshold, and four were suprathreshold. Two sets of instructions were used, identical to those used by Gregg and Brogden (1952). An extremely complicated pattern of results was observed; inhibition of auditory performance was observed at subthreshold light levels with instructions to respond to the light, but there was no effect with no instructions about the light. There were no effects of instructions at threshold. Facilitation occurred with suprathreshold light stimulation but was greater for the group not instructed to respond to the light. Gulick and Smith (1959) on the other hand, found no effect whatever of three levels of illumination on auditory acuity. They tested pitch and timbre discrimination in a homogenous visual field in darkness and under two levels of illumination. It may be instructive to reproduce here some of Thompson et al's (1958) concluding comments:

The outstanding feature resulting from consideration of the literature on the effect of visual stimulation upon auditory sensitivity is the lack of consistency in the results. Much of the inconsistency is due to inadequate experimental design and statistical treatment of the data. Some is probably due to the effect of parameters such as instructions, practice, and conditions relating to light stimuli and their mode of presentation. It is evident that the effect is small, and that it is altered by instructions given to S, by the intensity of the light at least between sub-threshold and suprathreshold intensities, and may be altered by other conditions. It appears unlikely that any precise functional relations exist between auditory acuity and simultaneous light stimulation and that detailed investigations pointed toward discovery of precise functional
relations are fruitless at the present time.

A more recent series of experiments again seems to show a facilitating effect of simultaneous light stimulation, this time on the variability of responding in an auditory localization task. Warren (1970) showed that for adult subjects, auditory localization in the frontal horizontal plane was more accurate (i.e., less variable) than it was in the dark. A group of sixth-graders in the study showed no effect of illumination on their localization performance. In Warren's experiments, subjects were required to point to the perceived location of a clicking sound under the two conditions of illumination (light and dark).

Warren and Judy (1972), in a study based on Warren's (1970) experiment, found a facilitative effect of visual stimulation on auditory localization with children. The purpose of this study was to elucidate the reason for the earlier failure to demonstrate the facilitation effect with children. The authors hypothesized that children were less likely to make eye movements directed toward the auditory target. Visual feedback training, in the form of a small light which appeared at the position of the unseen sound after the offset of the sound, was demonstrated to be effective in improving auditory localization performance.

Jones (1975), using a signal-detection paradigm, showed that schoolchildren did manifest the effect of visual facilitation of auditory localization. He found that latencies of the localization response to tones were
significantly shorter in the light than in the dark.

Platt and Warren (1972) extended these findings by examining the role of eye movements and visual texture in the visual facilitation of auditory localization. They conducted two experiments. In the first, subjects pointed to unseen auditory targets under one of the following three conditions: in the light with target-directed eye movements, in the light with eyes fixing a point, and with eyes closed. Eye position was monitored with skin electrodes. There was significantly less variability of the pointing responses in the eye movement condition than in the other two conditions. In order to investigate further the nature of the involvement of eye movements in the facilitation phenomenon, Platt and Warren conducted a second experiment. To determine whether eye movements per se were sufficient to facilitate localization, the third condition of the first experiment was altered. Where previously subjects simply closed their eyes in the dark condition, in the second experiment subjects were instructed to keep their eyes open and make eye movements toward the auditory target in a darkened environment. The other two conditions were the same as in the first experiment. By comparing performance in the condition with eye movements made in the light to the condition in which eye movements were made in the dark, it could be determined whether eye movements alone were sufficient to produce the facilitation effect or whether there must be a lighted environment for the eye movements to
be effective in facilitating performance. The results of this second experiment supported the latter conclusion. The pattern of variability and veridicality measures was similar to that in Experiment 1. The condition in which eye movements were made in the light produced significantly less variable and more veridical data than either of the other two conditions.

In the discussion of their Experiment 2, Platt and Warren outline a mechanism that might be responsible for the effect of visual input on auditory localization. They found that eye movements directed toward the auditory target were more veridical in the light than in the dark. These authors hypothesized that either (1) the presence of visual texture makes possible a relatively precise predetermination of the size of the saccade or (2) information from the amount of texture passed over during the eye movement gives more precise control over the saccade in the light. Presumably, the more accurate visual information obtained in the light via texture cues enables the subject to make a more precise localization of auditory stimuli.

It should be noted that this explanation of the facilitation phenomenon is of a somewhat different character than many previously advanced. Loveless, Erebner, and Hamilton (1970), in an excellent review of the topic, distinguish among four potential factors responsible for intersensory effects. The three relevant to this discussion are (1) specific intermodal connections (2) the alerting or
activating function and (3) temporal specification.

There seems to be fairly strong evidence of specific intermodal connections in the central nervous system of cats and goldfish. Thompson, Johnson and Hoopes (1963) found that stimulation delivered to the visual, auditory, or somatic sense receptors leads to an undifferentiated response in association areas of cortex. Hotta and Kameda (1963) found that cutaneous stimulation facilitated the response of thalamic cells to visual stimuli, but inhibited the response of these units to auditory stimuli. Murata, Cramer, and Bach y Rita (1965) recorded from cortical cells in areas 17 and 18 in cats. Many of these units in primary visual cortex were also responsive to sounds and pinpricks delivered to the paw. Spinelli, Starr and Barrett (1968) also found cells in cat visual cortex responsive to both visual and acoustic stimuli. Page and Sutterlin (1970) found units in the goldfish tegmentum that responded to both visual and acoustic stimuli. These cells exhibited sharply tuned frequency threshold functions. Sometimes simultaneous stimulation in two modalities resulted in a greater response than was observed when stimulation was from only one modality. In other cells, the reverse occurred; simultaneous stimulation of two modalities led to a response smaller than when the cell was stimulated in either modality alone. Fishman and Michael (1973) recorded from bimodally responsive cells in areas 17 and 18 of cat cortex. Many of these visual cells were most sensitive to pure tones, while
a few responded to a hiss. Of the cells that responded to pure tones, most showed a sharp frequency tuning while a few responded to broad bands of acoustic stimulation. The pure tone sensitive cells were also spatially tuned; auditory stimulation that originated from a position away from the location of the visual stimulus was not as effective in exciting the cell. Hiss-sensitive cells showed no such spatial tuning. Interestingly, Fishman and Michael found that bimodally responsive cells were located in distinct clusters separate from the unimodal cells.

The only two studies showing psychophysical effects consistent with the hypothesis of highly specific neural connections are those of Maruyama (1961) and Givotti and Peri (1963). These authors both found that stimulation of the left or right ear raised sensitivity in the contralateral half of the visual field and that visual stimulation had the same effect on auditory sensitivity.

The alerting or activating function of continuous, accessory stimulation may be the most widely accepted basis of intersensory phenomena. The physiological evidence relating to the excitatory and inhibitory functions of the reticular formation, which all sensory modalities can activate, is clear. Depending upon the parameters of the accessory stimulation, the alerting response should habituate rather quickly. This factor may have been operative in the experiment reported by Child and Wendt (1938) in which an intermodal facilitation effect declined
after the first few trials of the experiment and then disappeared. Other studies utilizing continuous, accessory stimulation (Hartmann, 1934; Gulick and Smith, 1959) have found both positive and negative results.

A closely related factor is that of temporal specification. In the cases where accessory stimulation is discrete and bears a fixed temporal relation to the stimuli in the testing modality, the accessory stimulus takes on cue value. The beneficial effects of having a cue to indicate when to start expecting the test stimulus are well known.

Most of the existing literature can be viewed as emphasizing one or more of the preceding three factors as an explanation for very general intersensory effects. The Platt and Warren hypothesis would seem to eschew the idea of a general explanation of intersensory effects in favor of an explanation which can account for the visual facilitation of auditory localization, and not of other auditory functions such as frequency discrimination. If their hypothesis that visual texture passed over during eye movements provides a more accurate visual localization and hence a more accurate auditory localization proved correct, it would then be important either (1) to explain how the general factors discussed above interact with the visual texture mechanism or (2) to explain which particular intersensory phenomena are covered by the general explanations and which have their own specific explanations.
However, there seems to be little empirical support for this hypothesis. Platt and Warren compared performance in a textured, lighted environment with performance in the dark. They sought to eliminate visual texture in a third condition by prohibiting eye movements in the light. The comparison between performance in a lighted, textured and a lighted non-textured environment, which would test for the importance of texture were directly, was not made. It would follow from their analysis that if texture cues in an illuminated environment were completely eliminated, then localization performance would no longer be less variable than performance in a dark environment. If, as Platt and Warren suggest, visual texture plays the central role in facilitating auditory localization in a lighted environment, then light-no-texture performance should not differ substantially from localization in a dark environment.

The present study sought to extend the findings of Platt and Warren by directly testing for the necessity of visual texture in the visual facilitation of auditory localization. By comparing performance in a ganzfeld condition, in which the subjects viewed a homogeneous visual field, to performance in a normally textured visual environment, the need for texture in the facilitation phenomenon could be determined. However, it proved impossible to replicate the basic facilitation phenomenon itself. That is, no reliable differences in performance between light and dark could be demonstrated, rendering the
question of the necessity for texture irrelevant.

The study then became an attempt to specify those conditions under which the phenomenon of the visual facilitation of auditory localization does and does not occur. Several experiments were conducted to determine what variables govern the occurrence of the effect. The response in the localization experiments was changed from a psychophysical judgement to one requiring the subject to point to the auditory target with a rod and finally to a manual pointing response similar to Warren's. Neither of these changes resulted in the occurrence of the effect. Both auditory and visual aspects of the stimulus situation were also altered. The auditory stimulus was changed from a pure tone to a click train. The visual background was changed from a grey sheet to khaki burlap to increase visual texture in the light condition. None of these changes were effective. Possible explanations for our failure as well as inconsistencies in the earlier literature are discussed later in this paper, as are suggestions for future research.
I. EXPERIMENT 1: Frequency Discrimination

The purpose of this experiment was to test the generality of the visual facilitation effect with respect to auditory functions other than localization. Frequency discrimination was chosen as the function to investigate. Frequency discrimination was measured under each of the three illumination conditions (light with texture, dark, and light without texture, or Ganzfeld) at 6 frequencies from 125 to 4000 Hz. It was expected that there would be no differences in sensitivity among illumination conditions, as the texture hypothesis assumes a spatial context for visual facilitation to occur.

Method

Subjects

Subjects were 30 undergraduates at the University of New Hampshire who participated in the experiment to fulfill a course requirement. There were 19 females and 11 males in the sample. Subjects reported no hearing losses or uncorrected visual problems.
Apparatus

Stimuli were computer generated on a DEC-10 digital computer and recorded on a Sony 4 channel tape recorder. The tones were presented through Telephonics TDH-49P earphones mounted in MX-41/AR cushions. Sound pressure levels were calibrated with a Triplett Model 370 sound level meter before each procedure was initiated. Subjects were seated with their heads at the opening of a Polymetric Co. Model V-1260-AR Rod and Frame Apparatus. This apparatus consisted of a 24" tunnel constructed of translucent acrylic 12 inches square in cross-section. The tunnel was rotatable but was fixed during the experiment. The apparatus was chosen because of the strong depth cues apparent when looking into it, and for the ease of controlling the illumination inside it. Illumination was controlled by moving two 15-inch GE fluorescent bulbs on two rails mounted on the Rod and Frame apparatus. Responses were recorded on a 4 channel event recorder via a push button. Experimenter and subject were seated in the same room.

Procedure

Frequency discrimination was tested at each of six standard frequencies for each subject. The standards were 125, 250, 500, 1000, 2000, and 4000 Hz. Stimulus loudness was held constant at 50 phons. Stimuli were presented monaurally to the right ear. The Method of Constant Stimuli was used to test frequency discrimination. The standard stimulus was paired with each comparison (and with itself)
10 times for a total of 90 trials. The stimulus duration was 1.5 sec and the time between two tones in a pair was .5 sec. The intertrial interval was 10 sec., and the temporal position of the standard alternated on successive trials. Figure 1 graphically illustrates this procedure for two trials with the 125Hz standard. Subjects were instructed to listen to each pair of tones and to compare them in pitch. They were to press one button, marked "HIGHER" if the second tone in a pair was higher in pitch than the first, and another button, marked "LOWER" if the second tone was lower in pitch than the first. These responses were recorded as pen deflections on two channels of the event recorder. Subjects were tested on two separate days; on one occasion the subject received three procedures, on the other, four. The procedures were presented in randomized order which was the same for all subjects. Comparison stimuli were presented in randomized order with the restriction that each comparison appear 10 times in a procedure. Subjects were randomly assigned to illumination conditions: 10 to Dark, 10 to Light, and 10 to Ganzfeld. Subjects in all three conditions were seated in front of the rod and frame apparatus; in the Light condition, subjects wore nothing over their eyes and were instructed to keep their eyes open during testing. In the Dark condition, subjects wore eye patches over their eyes and all lights were off. The windows in the room were sealed with black covers and puttyed at the edges to insur complete darkness. In the
Ganzfeld condition, sectioned ping-pong balls were placed over the subject's eyes. The edges of the balls were padded with cotton and the balls were secured over the eyes by a band of clear plastic wrap over the balls and taped at the back of the head. Care was taken to insure that this arrangement did not interfere with the earphones. The lights were adjusted (moved closer to the translucent walls of the Rod and Frame apparatus) to match the absolute level of illumination at the subject's eyes in the Light and Ganzfeld conditions. Calibration was performed with a Gamma Scientific Model 900 photometer. Subjects were instructed to keep their eyes open during testing. The fixation point for the subjects was the center of a black stripe on the far wall of the rod and frame apparatus.

Results

Individual psychophysical functions were constructed for each subject in each procedure. Thus, six functions, one for each standard frequency were obtained for each subject. Sample functions appear in Figure 2. A logistic transform (log p/1-p) was applied to these data, and an average function determined for each frequency in each illumination condition. A constant of .000001 was added to each datum to ensure that no values of 0 or 1 were entered into the analysis. The slope of the lines fit to these average functions with a Bi-weight fit to compensate for non-normal errors was used as the measure of discriminability. Figure 3 shows the discriminability,
expressed as slope, as a function of standard frequency in each illumination condition. It can readily be seen that no systematic differences among illumination conditions were observed. In fact, discriminability in the Dark condition was slightly higher than that in the light.

It should be noted that the slopes plotted here are not directly comparable to other results in the literature. Because the scales used were particular to this analysis, it is possible only to compare slopes across illumination conditions. The slopes have no meaning intrinsically. Discriminability was assessed using the midpoint of the interquartile range of the psychophysical functions, and results in agreement with Shower and Biddulph's (1931) study were found.
Figure 1. The temporal characteristics of stimulus presentation. The horizontal axis represents time; the vertical deflections of the dashed line indicate the presentation of a stimulus. Ninety trials such as these were presented to each subject at each standard frequency and in all three illumination conditions.
Figure 2. Sample psychophysical functions of four different subjects from Experiment 1. Percent "higher" is plotted as a function of comparison frequency. Comparison stimuli for the 125 Hz standard were 117 Hz, 119 Hz, 121 Hz, 123 Hz, 127 Hz, 129 Hz, 131 Hz, and 133 Hz. For the 500 Hz standard, comparisons were 492 Hz, 494 Hz, 496 Hz, 498 Hz, 502 Hz, 504 Hz, 506 Hz, and 508 Hz. Comparison stimuli for the 1000 Hz standard were 992 Hz, 994 Hz, 996 Hz, 998 Hz, 1002 Hz, 1004 Hz, 1006 Hz, and 1008 Hz. For the 4000 Hz standard, the comparison stimuli were 3980 Hz, 3985 Hz, 3990 Hz, 3995 Hz, 4005 Hz, 4010 Hz, 4015 Hz, and 4020 Hz.
Figure 3. Frequency discrimination curves from Experiment 1. Discriminability is measured as the slope of the lines fit to the average psychophysical functions across subjects at a given frequency and illumination condition. The circles show the light condition, the triangles show the dark condition, and the squares show the ganzfeld condition.
II. EXPERIMENT 2: Spatial Localization

A review of the recent literature on the visual facilitation of auditory localization revealed that in most studies that have demonstrated this effect, a manual pointing response was used. That is, subjects were required to point with their finger in the direction that they perceived the stimulus sound to be coming from. While attempts have been made to separate the possible confounding effects of manual response facilitation from purely auditory effects (Warren, 1970) it would clearly be desirable to demonstrate the effect with a procedure requiring no such response. It was with this goal that the present study was undertaken. A classic psychophysical method was adapted to the study of localization in place of the pointing response.

Method

Subjects

Subjects were 10 undergraduates at the University of New Hampshire who participated in the experiment to fulfill a course requirement. There were 7 females and 3 males in the sample. Subjects reported no hearing losses or uncorrected visual problems.
Apparatus

This study was conducted in a small sound attenuated room. The subject was seated at a small table with a chinrest mounted on it. In addition, a small piece of wire extended up from the chinrest assembly against which the subject placed his/her nose to reduce head movement further. An array of 9 1 1/2" Archer speakers was mounted on wooden dowels in front of the subject. These speakers were located on the perimeter of a circle of which the subject's head was the center. The radius of the circle was 24". The speakers were approximately at ear level in height. The center speaker was directly on the midline of the subject. The other speakers were placed at 10 degree intervals from this center speaker on both sides of it. Stimuli used were tapes produced in the same fashion as the tapes in Experiment 1. While the temporal relations of stimuli on the tape were identical to those in Experiment 1, the frequency of the tones was always 1000Hz. Tape output was routed through a Pioneer amplifier for intensity control and switched through a timer-stepper network to the 9 speakers. Nine potentiometers allowed individual intensity control over each speaker. The speakers were matched in intensity to within \( \pm 2 \) dB. All control and recording equipment was located in a control room adjacent to the testing chamber.
Procedure

Each subject was tested in all three illumination conditions; Light, Dark, and Ganzfeld. Order of presentation of the illumination conditions was counterbalanced across subjects. The method of constant stimuli was used in a manner exactly analogous to the procedure employed in Experiment 1. In this case, the center speaker was treated as the standard, and the 8 speaker positions on either side acted as comparison stimuli. Stimulus duration was again 1.5 sec, the time between tones in a pair was 1/2 sec, and the intertrial interval was 10 sec. Subjects were instructed to listen to each pair of tones and decide whether the second tone came from the right or the left of the first tone in the pair. Subjects then pushed one of two buttons to indicate their response. These responses were recorded in the same way as in Experiment 1. Subjects were tested on three separate days.

Results

The data were treated similarly to those in Experiment 1. Psychophysical functions relating "Percent Right" to speaker location were constructed. Sample functions for one subject appear in Figure 4. A logistic transform was applied to these data and a line fit to an average of these functions. An average slope for each illumination condition was thus obtained. Figure 5, a plot of these slopes as a function of illumination condition, clearly shows that there
were no differences in sensitivity as a function of illumination condition. A plot of the average percent correct for each speaker position appears in Figure 6. Because interaural time and intensity differences decrease as the midline is approached, spatial discrimination should be less accurate toward the midline than at the extreme speaker positions. This trend is clear in Figure 6.
Figure 4. Results for one subject from Experiment 2. The three curves, one for each illumination condition, show percent correct as a function of speaker position. The speaker positions are numbered from left to right: 1 is -40 deg., 2 is -20 deg., etc.
Figure 5. Spatial discrimination results from Experiment 2. This histogram shows the slopes of the psychophysical functions averaged across subjects at each illumination condition.
Figure 6. Average percent correct as a function of speaker position for Experiment 2. The speaker positions are numbered from left to right.
III. EXPERIMENT 3: A Signal Detection Approach

While the negative results in Experiment 2 suggested that the manual response may be important in the facilitation effect, it was clearly not conclusive. The lack of a finding of differential sensitivity under varying illumination conditions may only have shown that the psychophysical method used did not tap the subtler aspects of auditory localization. Accordingly, Experiment 3 was designed to provide a measure perhaps more sensitive than the discrimination procedure, that of reaction time.

Method

Subjects

Subjects were 10 undergraduates at the University of New Hampshire who participated in the study to fulfill a course requirement. There were 6 females and 4 males in the sample.

Apparatus

The apparatus was substantially the same as that in Experiment 2. A running time meter was added to the circuit to measure reaction times. A new stimulus tape was synthesized using the same procedures as for the earlier tapes.
Procedure

Single tones were used in this experiment instead of pairs of tones. The subjects' task was simply to push one button if the tone came from their right, and another if the tone came from their left. The tones were 1 sec. 1000Hz tones at 50 dB SPL. The subjects were instructed to respond as quickly as they could upon hearing the tone. Only eight of the speaker positions were used; the center one was not. Each speaker position was presented 10 times, for a total of 80 trials per illumination condition. Each subject was tested in all three illumination conditions on separate days in counterbalanced order.

Results

Two dependent measures were recorded: accuracy of responding and reaction time. Hit and false alarm rates were computed across stimuli for each subject and then averaged across subjects within each illumination condition. Figure 7 shows both average "hits" and "false alarms" as a function of trials for the three illumination conditions. There are no systematic differences in accuracy related to illumination condition. It can be seen from these data, however, that accuracy does decrease rather substantially as the experimental session progresses.

Figure 8 shows mean reaction time as a function of speaker position for each illumination condition. A two-way analysis of variance was carried out on the reaction times and a significant effect of illumination condition as well
as speaker position was found. Individual comparisons showed that Light reaction times were significantly shorter than Dark and Ganzfeld reaction times.
Figure 7. Average hit and false alarm rates as a function of number of trials in Experiment 3. Subjects answered the question, "Did the scurd come from the right side?". Hit rate is defined as the number of correct identifications (i.e., saying "yes" when the tone was on the right) divided by the number of trials when the tone was actually on the right. False alarms occur when the subject answers "yes" and the tone is actually on the left. The number of false alarms divided by the number of trials in which the stimulus was actually on the left is the false alarm rate. The circles show the light condition, the triangles show the dark condition, and the squares show the ganzfeld condition.
Figure 8. Mean reaction times as a function of speaker position in Experiment 3. Negative numbers refer to speaker positions on the subject's left, positive numbers to those on the subject's right. The circles show the light condition, the triangles show the dark condition, and the squares show the ganzfeld condition.
IV. EXPERIMENT 4: Rod Pointing with Right Hand

The results of Experiment 3 were seen as placing in doubt the visual facilitation effect as one involving an alteration of sensitivity per se, as it seemed that such an alteration would be accompanied by changes in the hit and false alarm rates across conditions. While it could be argued that a "ceiling effect" in Experiment 3 artificially minimized the differences among illumination conditions, the hit rates of 70% and false alarm rates of 45% at the end of the session seems to rule this out. It was considered desirable at this point in the research to retreat to an experimental arrangement as similar as possible to that of the studies which have found the facilitation effect in the past, in the hope of identifying those variables responsible for our failure to find the effect in Experiments 2 and 3. The present study was designed with this goal in mind. It was decided to use a more structured pointing response than was used in previous research, for two reasons. First, the arm does not pivot about the midline of the body, and this fact may introduce some constant error into the measurements. Secondly, there are several places at which the arm and hand may bend, contributing variability in the
direction pointed to from response to response. For these reasons, a rigid rod manipulated by the subject was employed.

Method

Subjects

Subjects were 10 undergraduates at the University of New Hampshire who participated in the experiment to fulfill a course requirement. There were 7 females and 3 males in the sample.

Apparatus

The same table and speaker arrangement as in Experiment 3 were used in this study. Stimuli, however, were 1000Hz pure tones which were presented through the switching apparatus from a Hewlett-Packard Model 200AB oscillator. The experimenter had manual control via a button over the onset and duration of the tone, as well as its speaker location. Stimulus intensity was 50 dB SPL. The response apparatus was also different. A 24" aluminum rod was mounted under the table such that it rotated the shaft of a potentiometer when it was swiveled from one side to the other under the arc of the speakers. An aluminum bar with a finger-hole in it was fixed to the rod 11" from the chinrest for the subject to put his/her finger through in order to manipulate the rod. The experimenter, seated in the control room, read the voltage from a digital voltmeter as the dependent measure. The position of the rod could thus be determined to an accuracy of slightly less than 1/2 degree.
of arc. A gray sheet was placed in front of the speakers to hide them from the view of the subject.

Procedure

Subjects were run on three separate days, receiving one illumination condition per day. Order of presentation was counterbalanced across subjects. Within each illumination condition, 6 trials at each of the eight speaker positions on both sides of the center were run. The subject was first familiarized with the response rod and then instructed to point the rod directly at the tone with his/her right hand when it came on, swiveling the rod back to the straight ahead position after the tone went off. The intertrial interval and stimulus duration were variable as the experimenter initiated each trial only after the subject had completed his/her previous response. Voltage readings were recorded manually by the experimenter.

Results

Figure 9 shows mean standard deviation of pointing responses as a function of speaker position for each illumination condition. A 2-way analysis of variance showed a significant effect of illumination condition, and of speaker position. Inspection of Figure 9 reveals that the effect of illumination condition is almost entirely due to the differences at the three right-most speaker positions. Here, standard deviations in the light were much lower than in Dark or Ganzfeld. Inspection of the individual data indicate that most of this effect can be accounted for by
one or two subjects with extreme scores.
Figure 9. Mean standard deviation of pointing responses as a function of speaker position for Experiment 4. The break at +10 degrees is due to an equipment malfunction which recorded responses at that speaker position incorrectly. The circles show the light condition, the triangles show the dark condition, and the squares show the ganzfeld condition.
V. EXPERIMENT 5: Rod Pointing with Left Hand

While the differences in Experiment 4 did achieve statistical significance, the particular pattern of responses was unsettling. The fact that the effect was largely due to differences at the right-most speaker positions, coupled with the large individual differences observed, seemed to warrant further investigation. It seemed possible that the use of the right hand in pointing was related to the fact of differences only on the right side. Accordingly, the experiment was repeated with the subjects using their left hands.

Method

Subjects

Subjects were 10 undergraduates at the University of New Hampshire who participated in the experiment to fulfill a course requirement. There were 6 females and 4 males in the sample.

Apparatus

The apparatus was the same as that used in Experiment 4.
Procedure

The procedure was the same as that used in Experiment 4, except that subjects were required to use their left hands when making their pointing responses.

Results

Figure 10 shows a plot of mean standard deviation of pointing responses as a function of speaker position for each illumination condition. A two-way ANOVA revealed no significant differences.
Figure 10. Mean standard deviation of pointing responses as a function of speaker position for Experiment 5. The break at +10 degrees is due to an equipment malfunction which recorded responses at that speaker position incorrectly. The circles show the light condition, the triangles show the dark condition, and the squares show the ganzfeld condition.
VI. EXPERIMENT 6: Rod Pointing Between Subjects

Given the negative results of Experiment 5, it was clear that a replication of Experiment 4 was in order. The study was therefore replicated, using a between-subjects design for ease of subject scheduling.

Method

Subjects

Subjects were 18 undergraduates at the University of New Hampshire. There were 7 females and 11 males in the sample.

Apparatus

The apparatus was the same as that used in Experiments 4 and 5.

Procedure

The procedure was the same as that used in Experiment 4 except that only two illumination conditions, Light and Dark were used and each subject was run in only one illumination condition.
Results

Figure 11 shows a plot of mean standard deviation of pointing responses as a function of speaker position for both illumination conditions. A two-way ANOVA showed no significant differences.
Figure 11. Mean standard deviation of pointing responses as a function of speaker position for Experiment 6. The break at +10 degrees is due to an equipment malfunction which recorded responses at that speaker position incorrectly. The circles show the light condition, and the triangles show the dark condition.
VII. EXPERIMENT 7: Rod Pointing with No Nose Pointer

Experiment 7 was an attempt to make the experiment even more like the earlier studies. No "nose-pointer" was used in the earlier studies. It was considered possible that a very small freedom in head fixation may have allowed for less accurate control of head position in the dark than in the light condition, and thus may have contributed to the reports of more variable responding in the dark. In Experiment 4, our "nose-pointer" may have minimized this source of variability. To test this possibility, Experiment 4 was replicated without the use of the "nose-pointer".

Method

Subjects

Subjects were 6 undergraduates at the University of New Hampshire who participated in the experiment to fulfill a course requirement. There were 4 females and 2 males in the sample.

Apparatus

The apparatus was the same as that used in experiments 4, 5, and 6.
Procedure

The procedure was the same as that used in Experiment 4, except that the subjects were not required to use the "nose-pointer" on the chin rest but were only instructed to keep their heads as still as possible. Only Light and Dark were tested.

Results

Figure 12 shows a plot of mean standard deviations of pointing responses as a function of speaker position for each illumination condition. A two-way ANOVA revealed no significant effects.
Figure 12. Mean standard deviation of pointing responses as a function of speaker position for Experiment 7. The break at +10 degrees is due to an equipment malfunction which recorded responses at that speaker position incorrectly. The circles show the light condition, and the triangles show the dark condition.
VIII. EXPERIMENT 8: Rod Pointing with Clicks

In a personal communication (Warren, 1980), it was suggested that the use of a pure tone as a stimulus and a lack of visual texture in the Light condition might be responsible for our failure to replicate the earlier findings. To test this possibility, a train of clicks was used as the acoustic stimuli (as in the earlier studies) and a piece of khaki burlap was substituted for the screen constructed with a sheet (also as in the earlier studies).

Method

Subjects

Subjects were 5 undergraduates at the University of New Hampshire who participated in the experiment on a volunteer basis. There were 3 females and 2 males in the sample.

Apparatus

The apparatus was substantially the same as that used in Experiments 4-7. However, the stimulus source was a click generator set to deliver 8 clicks/second at 50 dB SEL. A khaki burlap screen was substituted for the gray sheet in front of the speakers to increase visual texture in the Light condition.
Procedure

The procedure was the same as that used in Experiment 4, except that only Light and Dark were tested.

Results

Figure 13 shows a plot of mean standard deviation of pointing responses as a function of speaker position for each illumination condition. A 2-way ANOVA revealed no significant results.
Figure 13. Mean standard deviation of pointing responses as a function of speaker position for Experiment 8. The break at +10 degrees is due to an equipment malfunction which recorded responses at that speaker position incorrectly. The circles show the light condition, and the triangles show the dark condition.
IX. EXPERIMENT 9: Arm Pointing with Clicks

The only major difference remaining at this time between our procedure and Warren's earlier studies was the character of the pointing response employed. In this final attempt at replication, the rod was discarded and a more natural pointing response adopted.

The procedure in these studies leaves the duration of the stimulus and the intertrial interval up to the discretion of the experimenter, since the experimenter only initiates the next trial when he/she is satisfied that the subject has completed his/her response. Since it is possible that systematic differences in the time allowed a subject to respond could occur across illumination conditions, and thus produce an artifactual difference, stimulus duration and intertrial interval were monitored in this experiment to insure that this did not occur.

Method

Subjects

Subjects were 9 undergraduates at the University of New Hampshire who participated in the experiment to fulfill a course requirement. There were 6 females and 3 males in the sample.
Apparatus

The apparatus was essentially the same as that in Experiment 8. However, instead of pointing a rod at the sound, subjects pointed directly at the sound under a plexiglass shelf which was marked off at one-degree intervals. The subject could not see his/her arm or the speakers. The experimenter read and recorded the responses from the other side of the booth in which the subject sat.

Procedure

The procedure was the same as that used in Experiment 8.

Results

Figure 14 shows a plot of mean standard deviation of pointing responses as a function of speaker position for each illumination condition. A two-way ANOVA revealed no significant differences. There were no differences in mean stimulus duration for the two illumination conditions.
Figure 14. Mean standard deviation of pointing responses as a function of speaker position for Experiment 9. The circles show the light condition, and the triangles show the dark condition.
X. DISCUSSION

I was unable to test the major hypothesis of this study because I was unable to reproduce the visual facilitation effect reliably. The focus of the study thus shifted from determining the mechanism responsible for a very specific intermodal facilitation effect to the identification of the variables which govern the very occurrence of the effect. I altered both response and stimulus parameters systematically in an effort to identify the locus of the critical variable.

The first experiment was designed to determine the generality of the facilitation phenomenon with regard to auditory functions other than localization. Frequency discrimination was tested under three levels of illumination: light, dark, and ganzfeld. No differences in the discriminability of tones varying in frequency were observed across illumination conditions. Comparison of the observed thresholds with those of classic studies of frequency discrimination (Shower and Biddulph, 1931) showed a good degree of similarity.

Experiment 2 was designed to measure auditory localization performance under the same three illumination conditions. The method of constant stimuli was used to
eliminate possible confounding effects of the visual facilitation of the pointing response that might occur when pointing is used as the response to measure auditory localization. No differences in the discriminability of the spatial location of the tones were observed across illumination conditions. Thus we had failed to replicate the basic visual facilitation phenomenon of greater discriminability in the light than in the dark. It is interesting to note that though auditory localization should be least accurate at the midline, the variability of pointing responses was least on the midline. Because interaural time and intensity differences are minimized as sounds approach the midline, localization is normally much worse at the midline. There is a known effect of direction on positioning movements, however. Such movements are performed more accurately toward the midline (Fitts and Crannell, 1950). Since the stimuli only ranged forty degrees on both sides of the midline, the relatively small effect of position on localization was probably overshadowed by the effect of position on the pointing response.

It was thought possible that the classic psychophysical method used in Experiment 2 was not sensitive enough to show differences across illumination conditions. Jones (1975) had reported positive results in an experiment using reaction time as a dependent measure of auditory localization under different illumination conditions. Experiment 3 was conducted using reaction time as the
dependent measure. A small mean difference in reaction times was observed which did reach statistical significance. Reaction times were significantly faster in the light than in either dark or ganzfeld. There were no significant differences in accuracy (i.e., hit rate or false alarm rate) across illumination conditions. Since other studies had typically used fewer trials than we did, separate analyses of the accuracy data were conducted at several points in the experimental session. There were no differences in accuracy at 18, 36, 54, 72, or 100 trials. Inspection of the false alarm rates indicated that for the first 18 trials, false alarms were more frequent in the dark and light conditions than in the ganzfeld condition. Average reaction times for the first 18 trials were light, 1.24 sec.; dark, 1.10 sec.; and ganzfeld, 1.44 sec. Thus it appears that subjects were trading speed for accuracy in the light and dark conditions, at least over the first 18 trials. This is consistent with the view that no increase in discriminability of spatial location per se occurred in the light condition relative to the dark condition. A signal detection analysis along the lines of Jones' was performed by constructing latency ROC curves for each subject in each condition. The curves were uninterpretable and no systematic differences across illumination conditions could be discerned.

Since the facilitation phenomenon had not been produced using the method of constant stimuli, but had been using reaction time as the dependent measure, the possibility that
the former method was not adequate for these purposes was established. Experiment 4 was conducted using a modified pointing response to test this possibility. The pointing response was modified from simply pointing with the arm and hand to the perceived stimulus location because of the inaccuracies inherent in this method. The arm does not pivot about the midline of the body, and the elbow, wrist, and finger joints can all introduce slight variations in pointing topography from response to response. The modification consisted in having the subject swivel an aluminum rod which pivoted under his/her chin to indicate the perceived location of the stimulus. A significant difference in the variability of the pointing responses was observed. Responses in the light were less variable than those in either the dark or ganzfeld conditions.

While the facilitation phenomenon had apparently been replicated in Experiment 4, the extreme variability of the responses both within and between subjects was very unsettling. The fact that the significant difference across illumination conditions was almost completely accounted for by large differences at the three rightmost speaker positions also seemed strange. It was hypothesized that the fact that subjects had pointed with their right hands might be related to our observation of differences only on the right side. To test this hypothesis, Experiment 5 was conducted as a replication of Experiment 4 except that subjects were required to respond with their left hands. No
differences across illumination conditions were observed. Analyses at different numbers of trials were conducted, revealing no differences. An analysis of constant error instead of variability of responding also revealed no differences across illumination conditions.

At this point it became necessary to determine whether the differing results in Experiments 4 and 5 were indeed due to the difference in the hand used to point with or whether one of the results was simply a chance event. Experiment 6 was a straightforward replication of Experiment 4, except that a between subjects design was used. No differences across illumination conditions were observed.

Since the results of Experiment 4 now appeared to be merely a chance event, we began to search for differences in our procedure from those of earlier investigators that might be responsible for our failure to replicate their results. One such difference was our method of restricting head movement. In addition to a chin rest, a sharp piece of wire touched the nose of the subject to provide a reference for maintaining good head fixation. We hypothesized that with a less rigid method of head fixation, such as those used in earlier studies, there might be relatively poorer maintenance of a steady head position in the dark than in the light because of a lack of visual cues to mark the straight-ahead position. This would lead to artifically high variability in localization responses in the dark relative to the light. Experiment 7 was conducted with the
nce-pointer removed. No differences between the two illumination conditions, light and dark, were observed.

Warren (personal communication, 1980) suggested two other differences between our procedures. We used pure tones as stimuli, while he had used clicks, and we might not have had as much texture in our light condition as he had. We used a sheet to screen the subjects' view of the speakers, while he had used a piece of burlap. Experiment 8 was conducted using click trains as stimuli and a piece of khaki burlap as the screen. Again, no differences between illumination conditions were observed.

Perhaps the most obvious difference between ours and earlier procedures was our modification of the pointing response. As a final attempt at replication, we constructed a new apparatus which allowed us to use the same sort of pointing response that Warren had used. This consisted of a booth with a semi-circular plexiglass shelf 24" in radius extending away from the subject at about shoulder level. This shelf was marked off at one-degree intervals, enabling the experimenter to read the subject's pointing response as he/she pointed up under the screen. The speakers were suspended from a second 24" radius shelf at the top of the booth. A burlap curtain screened the subjects' view of the speakers. Despite the essentially complete similarity of our procedure to that of the earlier studies, no differences between illumination conditions were observed.
After this exhaustive attempt at replication of the visual facilitation of auditory localization phenomenon, we were forced to conclude that this phenomenon either does not exist or is of such a small magnitude as to render its demonstration problematical. The latter conclusion is favored by the existence of many positive findings in the literature. Why some researchers can produce the effect and others cannot is unclear. The diversity of methods we used in searching for this phenomenon would seem to have maximized our chances of producing it if it depended on some particular aspect of the procedure used in measuring it. About the best that can be said is that we have reproduced a sequence familiar to students of this literature: initial demonstration of an intersensory effect, followed by failure by others to replicate it.

While the evidence presented in this study permitted no clarification of the tangled and contradictory history of the intersensory facilitation phenomenon, our review of the literature did reveal some potentially promising avenues of investigation for future efforts. We noted above that Loveless, BreNER and Hamilton (1970), in their discussion of the alerting function of accessory stimulation, pointed out that the alerting response to continuous, accessory stimulation should habituate quickly. This was interpreted by them as evidence against the alerting function being primarily responsible for the results in the literature. If one assumes that intersensory facilitation in the case of
continuous auxiliary stimulation is a fact, then their conclusion may be justified. If, however, one accepts the contradictory evidence at face value, then it may be that habituation of the alerting response can help to explain some of the contradictory evidence. Heretofore unexplained contradictions in apparently similar studies may be explicable by looking for differences in procedures that might interact with the time course of habituation to produce such results.

One such procedural difference might be the state of adaptation of the subjects in these experiments. If all subjects in an intertrial experiment testing, say, the influence of light stimulation on auditory detection threshold were dark-adapted before being exposed to the experimental condition, one might expect an alerting response on exposure to light. On the other hand, subjects who were light-adapted before being given the experimental conditions might not show an alerting response on exposure to light and hence no facilitation effect, if they had waited in the light long enough for the alerting response to habituate. Other procedural differences possibly interacting with alerting response habituation might be the the number of trials used, stimulus duration, and intertrial interval.

Also, several studies, including the present one, have found that some subjects seem to show no effect or even a reversal of the facilitation effect. Thus, there may be a
subject variable involved in the effect. It seems clear that the detailed, analytic review of this literature, which is necessary if any critical variables are to be found to explain contradictory results, has yet to be done. This would appear to be the best next step in unraveling this literature.

It may turn out that the analytic review of the literature advocated above might reveal nothing so convenient as a pattern of procedures fitting it with a pattern of results. What are we to conclude if left with this mass of confused evidence?

It seems clear to this writer that there has never been unequivocal evidence for visual facilitation of auditory frequency or intensity discrimination. Thompson, Voss and Brogden (1958), Gulick and Smith (1959) and the present study all found results consistent with this conclusion. With regard to the visual facilitation of auditory localization, the series of experiments conducted by Warren and his colleagues showed positive (though not dramatic) results, while the present study failed to replicate them. Attempts by other laboratories might help to decide the issue.

One other approach to making sense of this literature might be to look carefully at the physiological evidence of interaction between sensory tracts and neural structures. While underlying neural organization is sometimes inferred from behavioral observations, this may be a case where the
reverse process might be fruitful. It does seem doubtful that our incomplete knowledge of neural function would allow us to make detailed behavioral predictions of the sort that would be useful, but the possibility is an intriguing one.

The foregoing suggestions are not intended to imply that the writer is convinced of the reality of intersensory facilitation effects. The fact that fifty years of at least occasional experimental investigation into the phenomenon have failed to produce any coherent and consistent results would make such a position uncomfortable. Nonetheless, it may yet be premature to abandon the effort to identify intersensory interactions. The multitude of studies reporting facilitating or inhibitory intermodal effects over the years cannot be easily dismissed. It seems unlikely that a spurious phenomenon could have remained in the literature so long.
REFERENCES


