THE UNIVERSITY OF MANITOBA

A SIGNAL DETECTION ANALYSIS OF THE EFFECT OF WHITE NOISE INTENSITY ON VISUAL FLICKER SENSITIVITY AND ON RESPONSE BIAS

BY

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DEDICATION

This research is dedicated to the memory of Professor John Peter Zubek who taught me to find out for myself.

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I would like to thank the members of my examining committee, Drs. R. S. Harrison, E. Schludermann, M. Janisse, H. Kelm, and especially Professor A. W. Pressey for the trust they displayed in giving me considerable freedom to explore an obscure phenomenon in accordance with my own philosophy of science.

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Abstract

In spite of several hundred published articles on the topic, the phenomenon of interaction among the sensory modalities has had little impact on the practice and theory of sensory-perceptual psychology. Recognition of these potentially important data has been hampered by conceptual narrowness, a dearth of systematic investigation, a surfeit of apparently contradictory results and methodological inadequacies. A review of the relevant literature indicates that sensory interaction (as reflected in altered sensitivity in one modality as a function of input in another modality) may be under the control of several inadequately investigated stimulus and subject variables. These include intensity of the auxiliary stimulus, temporal relations between the test and auxiliary stimuli, various qualitative aspects of the two stimuli, and state of sensory adaptation of the observer.

One sensory interaction condition which has received an unusual amount of attention is the effect of auditory stimulation on the Critical Flicker Frequency and in particular the effect of the intensity of auditory input on that measure of visual temporal acuity. Results of these investigations are suggestive of an attentional or arousal mechanism as mediator between the modalities. Careful research of a parametric nature is required, however, as research on the variables suffers from incomplete investigation and inadequate methodology.

The present research, employing methodology based on the Theory of Signal Detectability, assessed the effect of a wide range of

intensities of white noise on performance in a flicker detection task. Three subjects were exposed to 500 presentations of "flickering" or "fused" light under each of ten auditory conditions. Subjects rated on a four-point scale their confidence that they had observed a "flickering" light. Performance associated with each auditory condition for each subject was determined by deriving Receiver Operating Characteristic curves. In addition indices of sensitivity (d'_e) and of response bias (β'_e) were calculated for each subject under each auditory condition. Results indicated a reliable but complex interaction of intensity of auditory stimulation and visual temporal acuity. Peaks in sensitivity occurred at 40, 70, and 100 dB (SPL) of white noise while lowered acuity was found at 50 and 80 dB (SPL). No response bias was systematically and reliably related to noise level.

Results were discussed in terms of previous research, implications for existing and future theories of sensory interaction, and biological significance of interacting modalities. Suggestions for future research were presented including proposals for two studies designed in conjunction with the present research to determine the contribution of the arousal properties of the auditory stimulus.

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CHAPTER I

INTRODUCTION

Overview

The functional interdependence of sensory modalities has been the subject of considerable experimental attention during the last one hundred years. As a result, several varieties of intersensory phenomena have been tentatively identified. For convenience, these phenomena may be divided into two broad categories, "higher" and "lower" order intersensory effects (see Ryan, 1940, for a more detailed discussion). "Higher" order interdependence involves the interaction of the products of within-modality processing. In this category may be included multimodal input in concept formation, learning, and memory. "Lower" order intersensory effects involve the modification of processing in one modality as a function of activity in another modality. Multimodal determinants of the perception of space and size are perhaps the best known examples of lower order effects. Less well known, and certainly less well understood, are intersensory effects on very basic sensory-perceptual processes. Recently, intersensory effects have been shown in a reaction-time paradigm by Taylor (1974, Campbell and Taylor, 1975) and others. Taylor argued that improvement in visual reaction time with auditory stimulation represents interaction at the primitive sensory level rather than at the higher process or motor levels. A more direct approach, however, of assessing intersensory effects at the sensory-perceptual level, would be the psychophysical determination of sensitivity or acuity in one modality while a stimulus is presented to another modality.[1] It is not well known that literally hundreds of studies have been carried out employing this "auxiliary stimulation paradigm". These studies on the psychophysical determination of sensory-perceptual interaction between modalities (SI) form the background to the present work.

It is somewhat of a paradox that so large a literature as that on SI has had so little impact on sensory-perceptual psychology. For example, of the many textbooks available in the areas of Sensation and Perception only that of Dember (1965) discusses the possibility of sensory interaction. Similarly, only one major review paper has been published on the topic (London, 1954) and that dealt only with work done by Soviet researchers. The literature is apparently not well known even among researchers who have investigated SI effects, as their references are seldom complete. Another reason for the obscurity of SI may be the rarity of sustained systematic research. Typically, investigators perform a study or two and then abandon the topic. The Soviet research is an exception to this rule. London (1954) states, ". . . western work on sensory interaction has been, in the main, scattered and desultory, whereas in the Soviet Union the subject has been given systematic and sustained attention"[2] (p. 531). The western literature consists of a large number of disconnected but loosely overlapping studies. Interpretation of specific results is difficult as authors rarely take into account many potentially relevant variables and often provide only scanty reports of the experimental situation. Discrepancies between results are difficult to reconcile as studies are seldom designed to be comparable to other related research.

Researchers interested in SI effects, therefore, must try to extract from this unsystematic literature, clues as to the identity of relevant variables. Fortunately, the number of studies is large enough to allow a tentative picture of SI effects to be assembled from deductions and reasonable guesses.

Several interrelated factors seem to underlie the problems outlined above, and before reviewing the SI literature these reasons should be understood. In fact, such an understanding is indispensable if SI is going to be systematically investigated in the future.

There seems to be at least three interrelated reasons why the topic of SI has not become an important problem area in sensory-perceptual psychology. These are: (1) the lack of consistent results both in the experimental questions asked and in the expected answers to those questions; (2) the conceptualization of the sensory modalities as discrete functional entities as encouraged by the histories of sensory physiology and sensory psychology; and (3) an apparent reluctance to speculate on the usefulness to the organism of having modality interdependence at the sensory-perceptual level. Each of these reasons will be briefly examined.

SI research is an area with many apparent discrepancies in results. This may be due to over-simplistic expectations concerning the nature of the effects. Questions guiding research are often of the type: "What is _the_ effect of auditory stimulation on the absolute visual threshold?" Particular parameters of the stimuli and of the subject are not often recognized as possible contributors to differential effects. As a result, researchers expect simple answers such as: "The effect of auditory stimulation on the absolute visual threshold is to lower it." These overly simplistic expectations have caused many researchers to doubt the existence of SI effects. Parametric analysis may lead to the conclusion that such phenomena are extant but complex.

Historical considerations have limited the progress of knowledge concerning intersensory effects. Beginning with Muller's Doctrine of Specific Nerve Energies in 1838 the histories of sensory physiology (and thus sensory psychology) has largely been one of progressive isolation of function (Boring, 1942). Particularly influential have been the speculations of Helmholtz of which Boring (1950) said, "If Muller's theory is a doctrine of specific *nerve* energies, then Helmholtz's extension of the doctrine is a theory of specific *fiber* energies" (p. 91). Serious consideration of sensory interdependence goes against the spirit if not the edicts of the Helmholtzian tradition. Gestalt psychology represented a protest against this "isolationist" tendency. As Boring (1942) points out, however, for the Gestaltist, topics such as sensitivity were "swallowed-up" by the more molar concern of object perception.

There is no doubt that the predominant tendency in sensory-perceptual psychology has been to consider the modalities as discrete non-interacting entities. This may soon change, however, as psychologists become more aware of recent evidence from the area of sensory neurophysiology which indicates an unexpected degree and variety of convergence of the sensory systems. For example, a non-specific sensory system involving the reticular formation of the brain stem and mid-brain has been identified (see McCleary & Moore, 1965). This system receives collaterals from the major classical sensory tracts and generally arouses the cortex in response to sensory stimulation (Lindsley, 1961). Fuster (1962) has shown that electrical stimulation of this area in monkeys may result in changes in minimal separation time in a two-flash resolution task. These facts implicate the reticular formation as a candidate for the physiological mediation of SI effects. Other evidence indicates sensory system convergence in classical projection areas of the cortex. For example, the electrophysiological activity of the striate cortex has been reported to be altered at the gross and unit level in response to auditory stimulation (see, for example, Jung, Korhuber, & Fonseca, 1963; Skrebetski & Bomshteyn, 1967, 1968; Ciganek, 1966). The relationship between these neurological data and corresponding psychological phenomena awaits the establishment of unambiguous psychophysical description of those phenomena. As of now there are no general laws of functional interdependence that require neurological explanation. The physiological data should, however, serve to make psychological SI more plausible and so encourage the basic parametric research needed in this area.

The third reason SI research has not reached prominence as a problem area in sensory-perceptual psychology is that there is no obvious usefulness to the organism of interdependence at this basic level of functioning. Most researchers investigating SI effects seem either not to consider the biological significance of an interdependent organization of the sensory system or to consider SI effects as an epiphenomenon. As a result these effects have often been considered to be more curiosities of the laboratory rather than as part of the organism's adaptive process.

These reasons are, of course, complexly interrelated. Unless our conception of the sensory systems is widened to include interdependence, systematic research is not likely to take place, and yet the careful description of an instance of SI is just what is needed to widen the common conception. Until we have good parametric data describing SI effects their biological usefulness cannot be determined--and so on.

As mentioned above, a starting place in resolving these difficulties may be found in careful examination of the existing literature, unsystematic though it may be. The following section surveys the SI literature in an attempt to bring together, from a variety of sources, the most important information concerning the phenomena. As such the review does not exhaust the available literature but is rather an overview of the area, specifically, those variables which appear to be especially important.

Survey of the Variables Affecting SI

Historical Introduction

There is anecdotal evidence concerning SI dating from the 17th century. In 1669 the anatomist Bartholinius (cited by Hartmann, 1934) published his observation that the partially deaf could hear better in light than dark. It was not until 1888 that the first experimental investigations of SI phenomena were published by the

Austrian anatomist Victor Urbantschitsch. The work of Urbantschitsch has been extensively reviewed by Gilbert (1941) and the following discussion is based on that source. Urbantschitsch attempted to establish the heteromodal influence in all pairs of modalities, a task never before or since attempted, though as Gilbert suggests, ". . . it merely made up in scope what it lacked in thoroughness." It is to Urbantschitsch's credit, however, that his work represents a series of related studies. However suspect his results might be on methodological grounds they are therefore of more than historical importance. The results suggest that differential effects may be obtained with different values of several stimulus parameters. For example, he claimed that soft tones increased tactile sensitivity while loud tones inhibited it, and that loud tones initially darken but subsequently brighten the visual field. Qualitative aspects of the auxiliary stimulus were also recognized as determinants of SI effects. Thus high frequency tones were said to make colours brighter while low tones dulled colour intensity. In these demonstrations Urbantschitsch not only suggested the complexity of SI phenomena but he identified several stimulus dimensions as being important. Hundreds of studies later, the questions raised by Urbantschitsch are still in need of investigation.

The Role of Auxiliary Stimulus Intensity

Of all the variables that might affect SI results, there is more evidence concerning the role of the intensity of the auxiliary stimulus than any other. In contrast to the reports of Urbantschitsch, subsequent authors tended to see the effect of this variable as unidirectional. Thus, Heymans in 1904 (cited by Gilbert, 1941) authored the "Law of Inhibition" which stated ". . . the inhibitory power of a stimulus, measured by the intensity of a second stimulus which it can just completely inhibit, is directly proportional to its intensity." Heymans' "Law" described his own data showing electric shock to cause a decline in auditory sensitivity proportional to its strength. Another early study (Jacobson, 1911) found sensitivity to tactile pressure to be proportionally "inhibited" by increasing intensities of auditory stimulation. However, not all early research supported the "Law of Inhibition". Ode (cited by Gilbert, 1941) in 1919 found that weights felt heavier when hot or cold than at room temperature. Olfactory sensitivity was reported to be increased seven-fold in a lighted room over a dark room by Freund and Hofman in 1929 (cited by Hartmann, 1935). Performance on Seashore's auditory tests (Hartmann, 1934) and on a card sorting task that required tactile discrimination (Johnson, 1920) were similarly reported to be better in the light than the dark. Newhall (1923) reported brightness discrimination to be better concomitant with "clicks" than without. As only one intensity value of the auxiliary stimulus was employed in most of the above studies (e.g., the light was either "on" or "off") detailed functional relationships were not established. It is clear, however, that neither Heymans' "Law of Inhibition", nor any other description that is unidirectional describes adequately the heteromodal effect of the intensity of the auxiliary stimulus.

Two papers published in 1934 advanced the hypothesis that the effect of auxiliary stimulus was bidirectional, with the direction of effect being dependent on auxiliary stimulus intensity. Thorne (1934) reported that the probability of detection of a brief flash of light could be improved with a mild simultaneous noise from a buzzer. The detectability was made worse, however, with a loud noise from the buzzer. Thorne interpreted his results as a case of a figure-ground relationship. Vision, being the tested modality, was considered the figure, and audition was conceived of as "ground." Any "ground" of less intensity than the "figure" should enhance perception of the figure, while if the "ground" became very intense there would occur a figure-ground reversal (much as with a Rubin reversible figure). Mild auxiliary stimulation, then, should improve sensitivity in the tested modality while strong auxiliary stimulation would reduce sensitivity. Hartmann (1934), apparently without knowledge of the work of Thorne, also advanced a figure-ground theory of the heteromodal effects of auxiliary stimulus intensity "as figures, the auxiliary stimulus would raise thresholds in accordance with conventional expectations of the results of distraction, but as ground (with the main stimulus as 'figure') it may well produce facilitation."

Thorne and Hartmann, then, were the first since Urbantschitsch to suggest complex interactions in the production and direction of SI effects. Soviet researchers (as reviewed by London, 1954) have also (again apparently independently) noted differential SI effects with different intensities of the auxiliary stimulus. This effect is considered as a case of the "Rule of Inversion" which generally predicts reversed direction of results at different ends of several stimulus and subject continua. Thus, for example, visual sensitivity was found to be enhanced by mild odors and gustatory stimuli, while strong stimuli presented to the same modalities depressed sensitivity. Although the idea of some kind of figure-ground relationship is appealing it is far from established fact. What is required, but has been generally lacking, is the systematic investigation of several levels of auxiliary intensity on the tested modality with all other factors held constant. The one situation that has been studied more than any other in this regard is the effect of many intensities of auditory input on the critical flicker frequency (CFF). This literature will be reviewed in depth in a subsequent section; for now it will suffice to indicate that several investigators have independently concluded that the effect on CFF of increasing auxiliary stimulation intensity is oscillatory. That is, auxiliary stimuli progressively increase heteromodal sensitivity up to a point, then, with further increases in intensity, there results a progressive decrease in sensitivity. Although the role of the intensity of the auxiliary stimulus in determining SI effects is not clear, there is sufficient evidence of the importance of this variable to encourage its future systematic investigation.

The Role of Temporal Aspects of the Stimuli

Urbantschitsch found that a loud tone initially darkens but then lightens the visual field (Gilbert, 1941). This suggests that the temporal relation between the auxiliary and primary stimulus may be important in determining SI effects. Several studies have attempted to give precise statements concerning this relationship.

Child and Wendt (1936, 1938) reported that auditory sensitivity to a tone was enhanced by simultaneous presentation of a flash of light or if the light was presented 0.5 to 1.0 seconds before or after the auditory stimulus. This effect was not found if the auxiliary stimulus was separated from the test stimulus by 2 seconds. Similarly, Kuroki (cited by Gilbert, 1941) found auditory sensitivity to be maximal with simultaneous presentation of light and some increased sensitivity over a darkness condition was found when the light was presented up to 0.33 seconds before or after the test stimulus, but not for longer separations. In contrast, to the above, Pratt (1936) was unable to find changes in visual sensitivity if the auxiliary auditory stimulation followed the test stimulus. This apparent discrepancy may be due to the fact that the roles of test and auxiliary stimuli were reversed in the study of Pratt, or because of a great number of other differences in the studies. Matheson (1967) reinforced the idea that an auxiliary stimulus can act on a stimulus trace when he found that visual afterimages were prolonged when accompanied by auditory stimulation.

Soviet investigation of the temporal variable has dealt mainly with the cumulative effects of auxiliary stimulation (London, 1954). For example, the CFF was found to progressively increase during 15 minutes of exposure to white noise, thereafter it was found to decrease. Another Soviet contribution is the investigation of cessation effects--viz., the changes in sensitivity that accompany cessation of the auxiliary stimulus. Lowered sensitivity, it was reported, upon cessation of the auxiliary stimulus, may go through a hypersensitive phase before returning to baseline level; a hyposensitive period may follow enhancement.

The effect of temporal contiguity interacts with the variable of intensity in the production of SI effects. In fact the effective intensity may be partly determined by the temporal relation of the test and auxiliary stimuli. Gescheider and Niblette (1967) reported decreased sensitivity to tactile pulses to be progressively greater at 30, 50, 70, and 90 dB of an auxiliary "click". Greatest inhibition for each level of intensity was found at simultaneous presentation, with the inhibition approaching zero by 50 msec. The same investigators found similar results when tactile pulses became the auxiliary stimulus to the auditory "click".

The literature on auditory stimulation on the CFF is, in the case of temporal effects (as it is in the case of intensitive effects) particularly instructive. One unique contribution of this literature is the comparison of the effects of steady versus intermittent noise. Again, a thorough review appears in a subsequent section.

The temporal relation between the tested and auxiliary stimuli appears to be an important factor, with simultaneous or near simultaneous presentation optimizing SI effects. This factor may explain many apparent differences among data. For example, Kravkov (1934) claimed that the reason his data (showing changes in visual acuity with heteromodal stimulation) did not agree with that of Hartmann (1933) was because the latter did not space his trials adequately to allow for "return to baseline". Unfortunately, many such temporal aspects of the experimental situation are typically not reported.

The Role of Qualitative Aspects of the Stimuli

The 1930's saw a great interest in the relations among the senses from Gestalt-oriented psychologists. The literature generated, rather than arising from earlier research, seems to represent a separate tradition. The interest shown by Gestalt psychologists reflected their view of "unity of the senses" in which it is postulated that one set of qualities (e.g., "brightness and roughness") describes perception in all modalities (see Hornbostel, 1938). Attempts were made to alter qualities in one modality by altering the analogous quality in another modality. For example, auditory "brightness" was reported to "follow" visual brightness (Hartmann, 1934) and phi phenomenon was shown to follow intermittent auditory stimulation (Gilbert, 1938).

Qualitative aspects of the stimuli are seen as important determinants of SI effects by Soviet investigators (London, 1954). Evidently, the "Rule of Inversion" applies equally well to qualitative and quantitative variables. It was reported that while white and green light increased auditory sensitivity, red-orange light decreased auditory sensitivity. Peripheral visual sensitivity has also been found to vary under heteromodal stimulation as a function of the wave length of the test stimulus. Auditory stimulation increased sensitivity to green light and decreased sensitivity to red light. No change was reported for extreme violet or yellow wave lengths. The situation is made more complicated by another Soviet study which purports to show a reversal of the above when foveal vision is tested. In addition, odors judged as "pleasant" improved visual sensitivity while "unpleasant" odors depressed sensitivity. Again, the Soviet research must be viewed with caution (see footnote 2), however, these findings of changes with qualitative differences should encourage systematic research.

Other Stimulus Factors

It is probable that a number of other stimulus variables are involved in SI effects. The identification of many of these factors awaits future research. One topic that has only been investigated in one study and yet would seem important is the complexity of the auxiliary stimulus. Matheson (1967) reported that the complexity of the auxiliary auditory stimulus was a factor in determining the vividness of visual afterimages. As with "intensity", increasing complexity was found to progressively facilitate afterimages to a point, and thereafter to decrease the vividness of the afterimage.

Up to this point the search for general laws of SI has ignored possible differences between particular combinations of stimuli. The implicit assumption that the laws of (say) the effect of audition on vision apply equally well to the effect of vision on audition, and so on, may not be warranted. Taylor(1974) has claimed that while auditory input facilitates visual reaction time, the opposite has not been found to be true. The results of the psychophysical data are more complex. With these data the investigator is faced with questions such as: "What is the intensitive equivalent in vision of a 90 dB