THE EFFECTS OF AUDITORY STIMULATION ON VISUAL BRIGHTNESS

by

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I. INTRODUCTION

Of considerable significance for our understanding of the general nature of sensory experience is the problem of the relationships existing between the various qualitative aspects of sensory consciousness, i. e., between the several senses. Conventional views of sensory experience from the time of Aristotle to the present have held that there is a sharp distinction between the particular senses. It has not been until quite recently that it has become apparent that a strict application of such a viewpoint does not provide an adequate theoretical structure for the facts of sensory experience, and it has become clear that the problems involved in the doctrine of the qualitative specificity of the particular senses must be considered more fully. This involves a new emphasis upon the close relationships existing between the different senses.

The logical difficulties which immediately arise upon the assumption of experience as a congeries of several discrete types of sensory experience are among the most significant of the factors which are responsible for this new interest in the nature of the inter-sensory relationship. If the several senses are posited to function in complete independence of one another, each operating in such a way as to have no influence of any sort on sensations of the other modalities, it is quite obvious that the most pronounced aspect of experience, namely, its unitary character, remains unaccounted for. The assumption definitely demands discrete and isolated modes of experience with no organization or unity of their own.

The logical difficulties of this position were early recognized. Attempts to meet the problems involved have taken the form of a postulation of some higher agency which was supposed to impose unity and coherance on experience. This is what Aristotle did in his assumption of the sensus communis, and theorists who have held to this same original assumption of sensory elementarism have ever since been forced to rely upon some similar device to give unity to an experience which is actually highly unified and which is unorganized only in terms of such original assumptions. It is obvious that such an assumption as that of a higher agency is a makeshift arrangement intended to patch up a gap in the general theory, and the importance of such a conception as this higher agency would seem to lie mainly in the fact that it is a recognition of the inadequacies of any viewpoint which considers the senses as elemental entities.

Developments in the fields of empirical science have further suggested that sensory experience is something more than what this somewhat barren theory of sensory discreteness represents. For example, theoretical consideration of sensory problems during recent years has turned more and more to an emphasis upon factors of central determination as being of primary importance in sensory processes. Additional evidence from the field of neurology, indicating that the neurological processes underlying conscious phenomena are themselves highly unified, makes it seem highly probable that the neural centers involved in the mediation of different types of sensory experience are closely connected with one another.

More convincing, possibly, than abstract logical arguments or the evidence from other empirical sciences is the mass of evidence on this point which has been gathered during the process of psychological research. While one might be perfectly willing to admit the cogency of the logical arguments on the impossibility of regarding the senses as completely separate, he would still be obliged to consider the possibility that these logically demonstrated inter-sensory influences might be so small as to be unnoticeable. In other words, while it would seem, on the basis of pure logical deduction, that some sort of relationship must exist between the senses, it does not necessarily follow that one sense must influence another to such a degree as to become recognizable in consciousness. The different senses of the average observer, for example, operate fairly independently of one another, and he recognizes no brightnesses changes in the visual field which come about as a result of simultaneous auditory stimulation. Changes, if any, are extremely small. In order to permit any small changes to show up, therefore, it is necessary to carry out carefully controlled experimental tests on normal, non-synaesthetic observers. We shall now consider some of the experimental evidence which indicates that such effects actually do exist to a definite and appreciable degree.

1. Historical Survey

As early as 1888 Urbantschitsch (11) reported that concomitant auditory stimulation results in a heightening of color sensations in such a way that colors previously not perceptible are raised above the threshold and recognized. This effect of heightened excitation lasts for a few seconds after the cessation of the tone. Pitch and, to a lesser degree, intensity were found to be the most important auditory factors, high frequencies and intense stimulation giving optimal facilitation. Urbantschitsch further found that each sensory modality has an influence on every other field of sensory experience. These results were confirmed in the main by Tanner and Anderson (10) a few years later.

More recent work by Lasareff (5, 6, 7, 8) substantiates the results of Urbantschitsch with respect to the influence of sound on visual perception as well as those with regard to the reversed effect of visual stimulation on auditory experience. Lasareff attempts to account for this reciprocal influence between audition and vision on the basis of his ionic theory of excitation, which assumes that changes in ionic concentration take place in the nervous system of one sense as a result of changes in the ionic distribution in the nervous field of the other sense.[1]

Interesting and significant results along the line of brightness facilitation in the presence of auditory stimulation are reported by Newhall (9) in connection with his account of experiments designed to deal with the effects of attention on sensory experience. He says that there is a "tendency for more stimuli to be judged super-threshold and the magnitude of brightness to be judged greater when auditory stimulation in the form of sharp clicks are simultaneously presented.[2] So pronounced were these brightness increases which accompanied the auditory stimulation that one observer complained that the apparent fluctuations of brightness of the objectively presented visual field so disturbed him that he felt he could no longer make accurate judgments with respect to the objective visual field because this "illusory" brightness could not be distinguished from the subjective brightness aroused by the visual stimulus field itself. This observer characterized the fluctuations as "illusory and due to the clicks". These fluctuations disappeared upon discontinuance of the clicks. Newhall tries to account for this facilitation by ascribing it to a higher degree of attention which the additional auditory stimulation calls forth.

Quantitative research bearing on the influence of auditory stimulation on a somewhat different aspect of visual experience than that involved in the preceding researches has been undertaken by Kravkov (4), who has investigated the effects of auditory stimulation on visual acuity. Marked differences between visual acuity under auditory stimulation and acuity without the influence of sound are reported. It is indicated that visual acuity is increased through the induction of sound in the case of black test objects on white ground in extent varying from 15 to 44 percent for nine of ten observers. Facilitative effects gave way to inhibitory influences when white test objects on a black ground were used, however, Kravkov reporting a decrease in acuity ranging from 7 to 70 percent in all of his observers. No attempt is made to account for these opposite effects when the object-ground relations are reversed.

Quite recently Zietz (15), working with non-synaesthetic subjects, has studied various forms of experimentally induced synaesthesia, paying particular attention to the influences of sound on after-images and of brightness of illumination on apparent pitch. Using tones of 200, 500, and 1100 vibrations per second in conjunction with visual material presented in various ways, he reports pronounced effects upon the course of the after-image, entailing modification of the latter in contour, brightness, and in other qualitative characteristics. So outstanding were these effects that the after-image had a tendency to "follow" the tone, in such a way that the after-image would flicker when the tone was sounded intermittently. The character of the visual experience seemed to be significantly determined by the pitch of the tone; a tone with a vibration frequency of 200 per second would cause the color of the after-image to appear darker, softer, warmer, and indefinite contours, while a tone of 550 would give rise to an experience in which the image was cooler, clearer, brighter, and of more definite and sharp outline. At times, according to Zietz, a rounded after-image would take on a form approximately square under the influence of the highest frequency used, 1100 vibrations per second. A complementary research, in which the influence of light, darkness, and the color of the surroundings upon pitch discrimination was tested, indicates that a tone sounded in a lighted room is estimated as higher than one sounded in the dark.

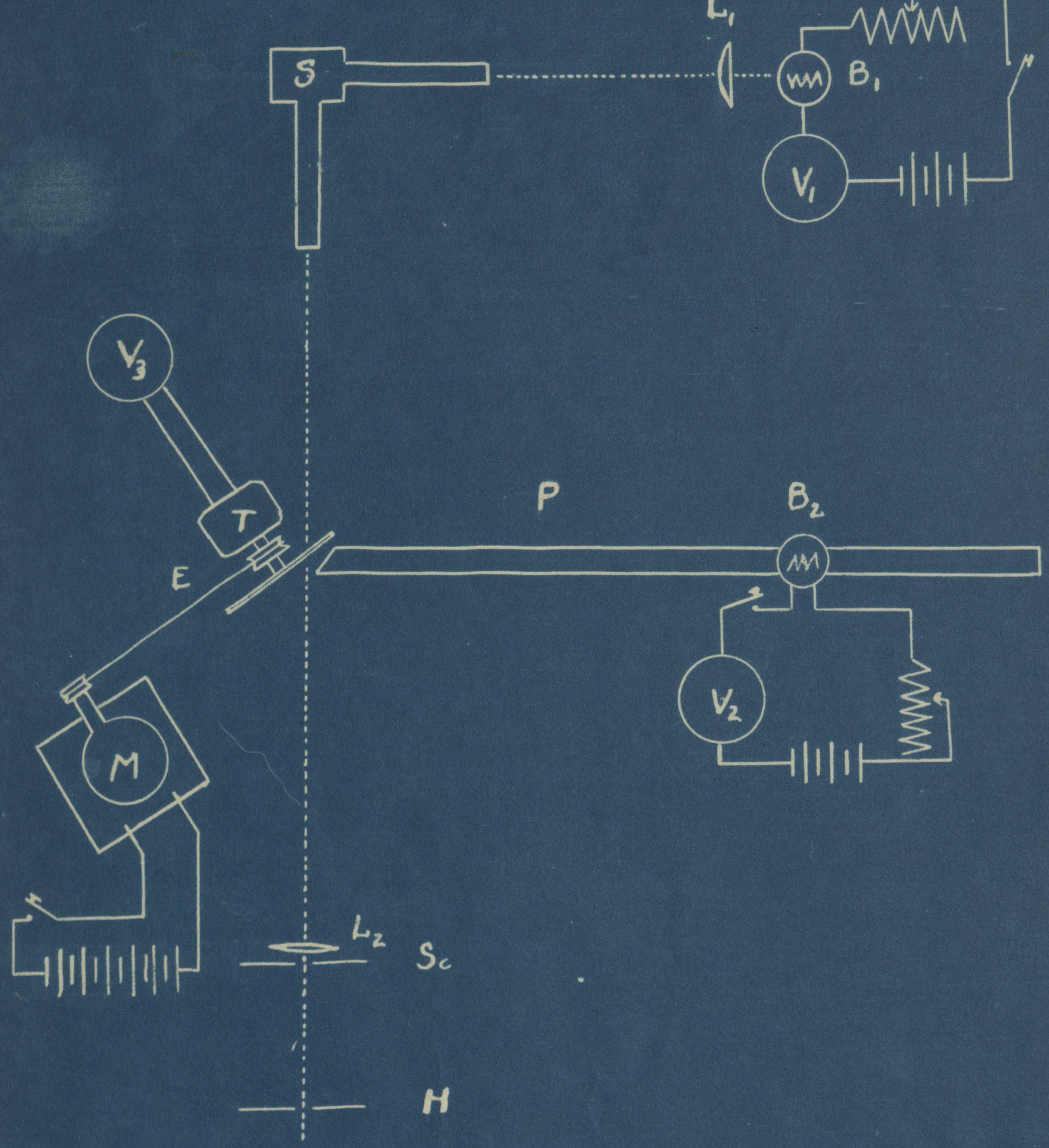
Finally, it should be pointed out that the whole literature on synaesthesia bears directly on the problems involved here. There is no essential difference between the inter-sensory effects such as we have reviewed for ordinary non-synaesthetic observers and the inter-sensory effects that mark an individual as a synaesthetic type, except in degree and variety of types. Synaesthetic phenomena of all types are simply exaggerated forms of what are in essence the same sort of mutual influences between the several senses, which we have just reviewed. In both instances, in the case of the "normal" individual and in the case of the synaesthetic individual, there is an eliciting of sensory impression in one sensory field as a consequence of direct stimulation of what conventional sensory theory has regarded as a separate and discrete sense organ, but these phenomena are so vivid, so outstanding, and so important in the sensory experience of the synaesthetic individual, so sharply deviating from the relatively compartmentized sensory experience of "normal" observers, that they have been considered anomalies of sensory experience. The experimental work we have considered above, however, emphasizes the point that these inter-sensory influences are not abnormal forms confined to a relatively small number of individuals, but that they are a fundamental aspect of sensory experience, and as such are present to some degree in almost all observers. We shall consider the theoretical implications of this viewpoint more in detail later on. For the present it is sufficient to point out that phenomena of the type reviewed above must be considered, if careful experimental work confirms their existence, as in effect experimentally induced types of synaesthesia in individuals of normal sensory experience.

2. Statement of the Problem

The results of all of the above-mentioned experiments point very strongly to a close functional relationship between the different senses, a relationship which is more than simple logical deduction and which apparently exists in a definite degree in normal sensory experience. The large variety of phenomena reported, all of which involve stimulation from one field serving to call up definite phenomenal changes in other fields, indicates that these inter-sensory ramifications are quite extensive and involve many types of response. It is the purpose of the present research, however, to confine itself to a relatively limited portion of this field, namely, that of brightness changes which may accompany simultaneous auditory stimulation.

This aspect of the problem would seem to offer the greatest possibilities for definite results, since measurements with respect to visual brightness can be made with a considerable degree of precision. Of the experiments we have outlined above, Newhall and Zietz specifically mention definite brightness changes in visual experience when auditory stimulation is induced, while in the reports of Urbantschitsch, Tanner and Anderson, and Lasareff mention is made of color intensification in such a manner as to raise what before the induction of sound were sub-liminal colors to a point above the threshold, so that the color could be distinguished. In the case of these last-named investigators it is not necessarily true that these changes involve increases in brightness, as it is remotely possible that other aspects of visual experience are changed. It is hardly likely, however, that this latter possibility is true, so that the work of these three may be interpreted as evidence that brightness changes take place under the influence of simultaneous auditory stimulation.

This research is intended, therefore, as an attempt, from a somewhat different angle and under considerably altered conditions from those of preceding investigations, to determine what changes, if any, take place in the apparent brightness of an objectively presented visual field of a definite, measured brilliance when auditory stimulation is introduced into the total perceptual configuration. An attempt to get away from the gross inaccuracies of purely subjective estimations of visual brightness and to attain more objective estimations of visual brightness was made through the use of the method of critical frequency of fusion. If definite evidences of inter-sensory influences can be found to exist in normal, non-synaesthetic observers under carefully controlled experimental conditions, it is possible in this way to determine by measurement the extent to which they are present.



S
L1
B1
V1
V3
P
B2
T
E
V2
M
L2
Sc
H

LEGEND

H	Headrest	S	Spectormeter
Sc	Screen	L_1	Lens
L_2	Lens	B_1	Source Lamp
M	Motor	V_1	Voltmeter
E	Episcotister	B_2	Standard Lamp
T	Tachometer	V_2	Voltmeter
V_3	Voltmeter	P	Photometer Bench

II. CONDITIONS OF THE EXPERIMENT

1. Apparatus

Plate I shows the general arrangement of the photometric apparatus. Spectral light of any given wavelength was supplied by the constant deviation spectrometer, S. A rheostat connected with the source lamp, B_1, provided a means of varying the intensity of the spectral light. The measure of intensity in photons of the light field produced by the spectrometer was obtained through equation of this field with light from the standard lamp, B_2, on the photometer bench, P.

Light coming from the spectrometer passed through a small circular opening in the screen, Sc, so that the field which was presented to the observer at the headrest, H, subtended an angle of less than one degree, so that stimulation took place well within the fovea. A small black point in the center of the diffusing lens, L_2, served as a fixation mark. The effective pupil area was held constant throughout all of the observations through the use of an artificial pupil.

Subjective brightness readily measured through determination of the rate of rotation necessary to extinguish flicker when the epistotister, E, consisting of a disc with two open quadrants, interrupted the line of vision.

An audio oscillator producing sound waves from below the audible limits to approximately 25,000 vibrations per second was used to supply the auditory stimulation. By means of the rheostat the intensity of the sound was controlled with a fair degree of accuracy throughout all ranges of pitch.

2. Method

It was found soon after the preliminary experiments were made that any changes that might result from the induction of sound are quite small, so small in fact that, if they were to be revealed at all, a considerable degree of precision in making judgments of the fusion point had to be attained by the observers. For this reason the observers were required to make a large number of preliminary practice judgments, until the average deviation for a given series was reduced to a minimum.

Particular care was taken to eliminate any error which might result from fatigue or other disturbing physiological factors. It was necessary, therefore, to make only a limited number of observations at one time. A further precaution was found to be necessary when it became apparent that daily changes in the fusion point for a given brightness are of such magnitude as to make it impossible to measure any small changes that might result from the auditory stimulation itself. In order to rule out this conflicting influence, both the series without sound and that with sound were made at the same time. Generally the series without sound was made first, but, if the series with sound preceded the other, several minutes were permitted to elapse between the two series in order to preclude the possible factor of persistence of physiological and psychological effects after the cessation of the sound.[4]

For the reasons suggested above, the statistical averages recorded represent fewer numbers of observations than might otherwise be desirable, generally embracing from 10 to 20 individual judgments. However, the validity of the figures recorded is strengthened by the fact that the data from large numbers of observation made during the course of practice shows for all of the observers a substantial agreement with the results of the observations recorded, if allowance is made for discrepancies and inaccuracies which are due to inexperience.

Since precision in making fusion point determinations depends upon the skill with which the observer can differentiate the stages in the flicker-fusion continuum and on the constancy of the observer's criterion, abilities which could be acquired only through a considerable amount of practice, it was necessary to limit the number of observers to a smaller number than would otherwise be used. It was the original intention of the experimenter to use only three observers, but it soon became obvious that a greater number would be needed. The following seven observers, all of whom have had training in observation of psychological phenomena, were used during the course of the experiment: R. L. Brigdon, M. G. Cutsforth, H. R. DeSilva, Beulah M. Morrison, B. C. Sarvis, R. H. Wheeler, and the writer.

It might be pointed out that the hum of the motor used to drive the episcotister introduced an extraneous sound into the experiment which could not be eliminated. The character of this sound was low and fairly constant, however, so that its presence was not particularly noticeable. It must be remembered, therefore, that during the observations which were taken without auditory stimulation from the audio oscillator there actually was some slight auditory stimulation, so that what the series in which the tone from the oscillator was operating represents is a change in the relative amount of sound stimulation, particularly with respect to the intensity and pitch. The experimental results clearly indicate that the introduction of the controlled sound did have an effect which was due to its character, i. e., its greater intensity and higher pitch as compared with the background motor hum. It would be worthwhile to carry out similar experiments in a soundproof room and with a muffled motor in order to ascertain whether under such optimal conditions more pronounced differences between the two series would be obtained.

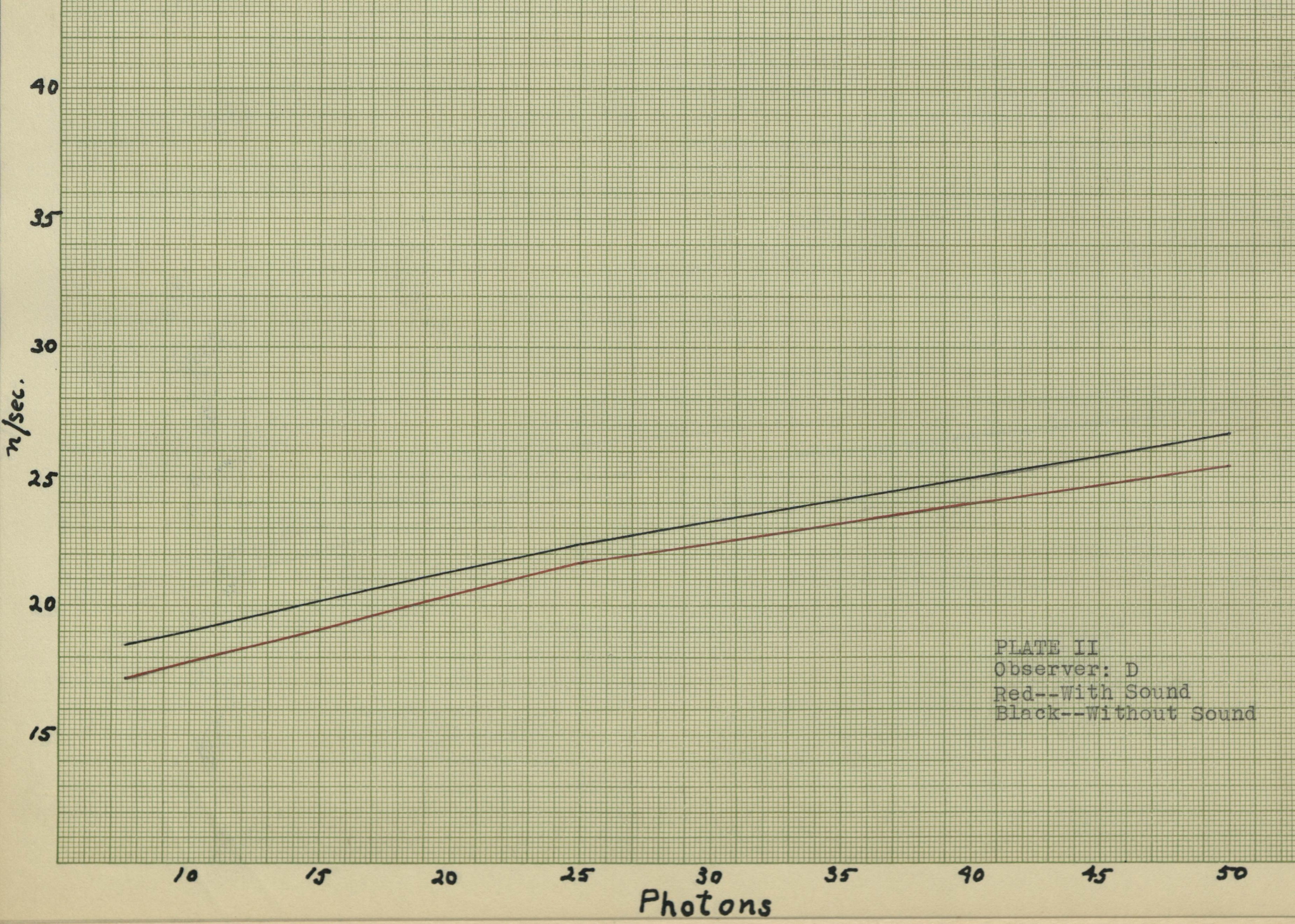
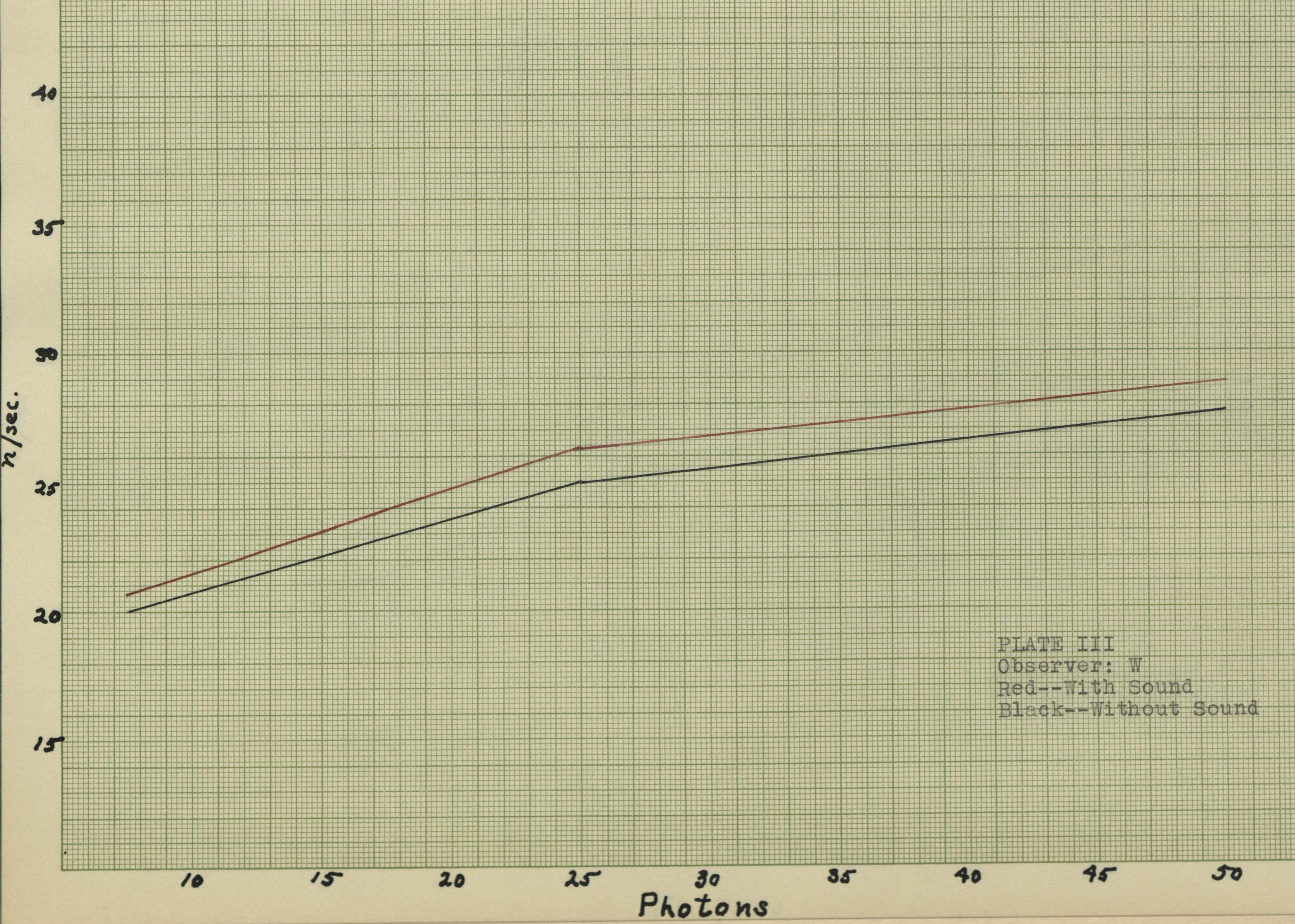


PLATE II
Observer: D
Red--With Sound
Black--Without Sound
n/sec.
40
35
30
25
20
15
10
15
20
25
30
35
40
45
50
Photons



40
35
30
25
20
15
n/sec.
10
15
20
25
30
35
40
45
50
Photons
PLATE III
Observer: W
Red--With Sound
Black--Without Sound

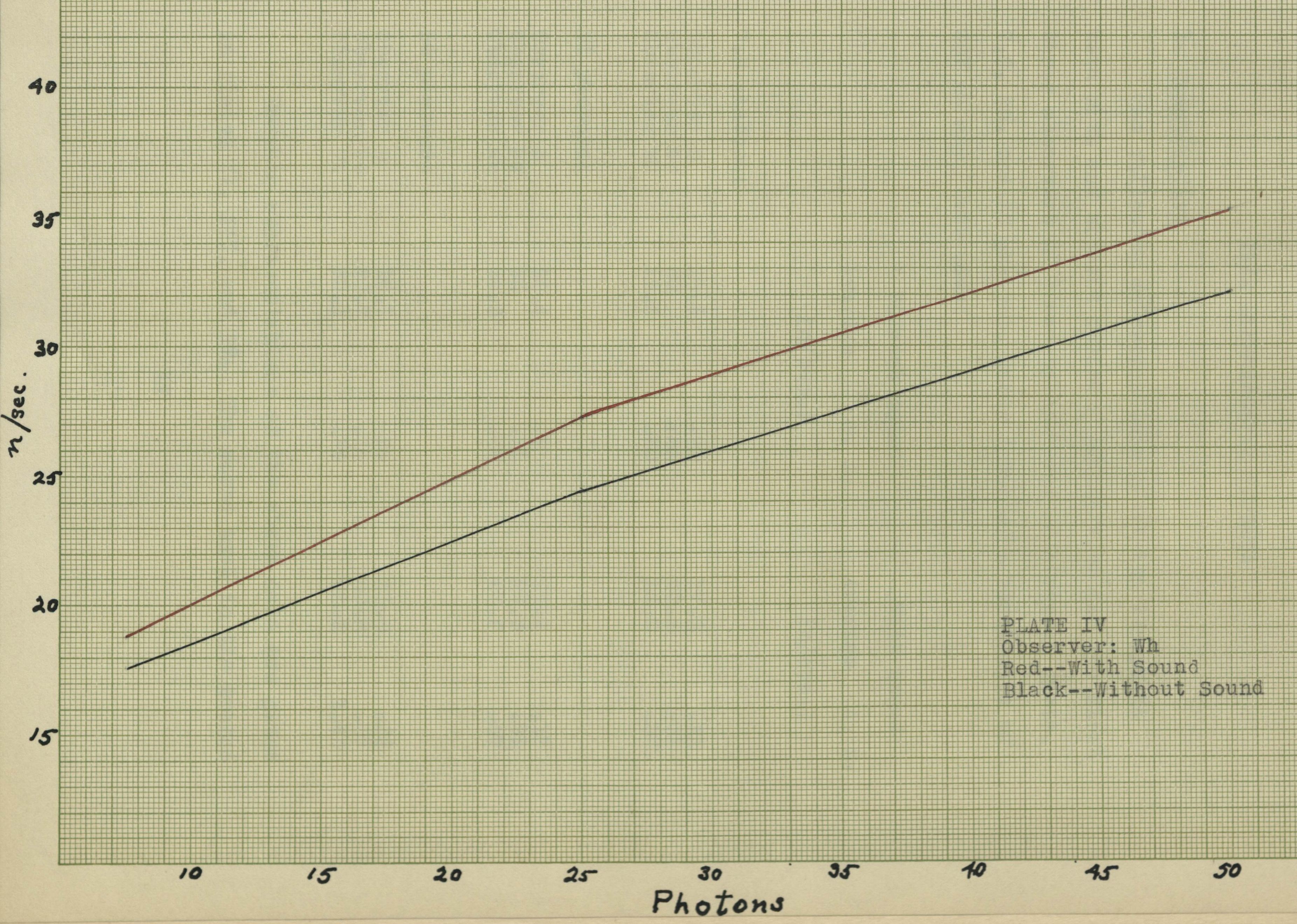


PLATE IV
Observer: Wh
Red--With Sound
Black--Without Sound
n/sec.
40
35
30
25
20
15
10
15
20
25
30
35
40
45
50
Photons

III. EXPERIMENTAL RESULTS

1. Quantitative

The following determinations of fusion threshold both with and without auditory stimulation for the first three observers at three intensities of a visual field, 7.5, 25, and 50 photons, using light of a wavelength of 687 mu mus, were made:

	Without Sound		With Sound	
	Average (n/sec.)	A. D.	Average (n/sec.)	A. D.
7.5 photons:				
Observer D	18.5	.31	17.2	.21
Observer We	20	.28	20.6	.21
Observer Wh	17.6	.30	18.8	.58
25 photons:				
Observer D	22.4	.1	21.6	.17
Observer We	25	.21	26.3	.31
Observer Wh	24.5	.44	27.2	.47
50 photons:				
Observer D	26.7	.24	25.4	.36
Observer We	27.7	.16	28.8	.37
Observer Wh	32.1	.74	35.3	1.42

Graphic representations of the above data are given in Plates II, III, and IV. The sound used in the second series, it should be explained, was moderately intense, but not so strong as to be uncomfortable, and of a frequency of 2000 vibrations per second.

It will be observed from these data that in the case of two of these observers, W and Wh, auditory stimulation gave rise to an increase in the rate of flicker necessary to produce fusion, amounting for both observers at all intensities of visual stimulation to several times the value of the mean variation. We may conclude, therefore, that for both of these observers there was a measurable increase in subjective brightness which may be attributed to the influence of the auditory stimulation. The results in the case of the third observer, D, are directly the opposite of these, however, exhibiting quite as definite evidences of a lowered fusion threshold in the sound series as there are evidences of increases in the others.

This puzzling difference in the reactions of the observers led to a further investigation of the character of the response of the single observer who reacted to the sound with a lowered fusion point. The first possibility that suggested itself was that the pitch, which is stressed in the earlier researches as the important factor in influencing visual brightness, the high pitches giving the greatest brightening while lower pitches are reported frequently to give the opposite effect, was a relative rather than an absolute factor. In other words, it might be that this particular individual reacts to a tone of 2000 vibrations per second in the same way that others are reported to react to a tone of several hundred vibration per second. If this hypothesis is true, it should follow that a pitch relatively higher than 2000 per second would produce a brightening effect. The brightness response of D was therefore tested under conditions of varying pitch, particular emphasis being placed on the effects produced by the frequencies between 4000 and 6000 per second. Brightness and wavelength were held constant. The following results were obtained using sound waves of 500, 4000, and 6000 per second:

Without Sound	500/sec.	4000/sec.	6000/sec.
26	23.8	23.2	23

It will be observed that the highest pitches did not produce a brightening subjectively, but that the opposite was rather the case, there being a distinct dimming of the visual field as the pitch of the tone was increased. The consistency of this observer's results indicated that the induction of the tone actually did result in a lowering of the flicker point necessary for fusion as far as this observer was concerned.

Further consideration of the possible basis for the unexpected dimming in the case of D suggested that other quasi-synaesthetic effects might arise in this observer to overwhelm and cancel any possible brightness increase which might result from the tone itself. Among those conditions frequently reported by synaesthetic subjects as resulting in a subjective darkening is that of intense kinaesthetic strain.[5] The possibility that for this observer kinaesthetic strain be the dominating factor responsible for subjective dimming was tested by having D make two series of observations, one without sound, to serve as a standard, and the other while the musculature of the observer's body was strongly contracted. Under these conditions it was found that the fusion point under kinaesthetic strain was 25.8 (A. D., .28) as compared with 26.5 flickers (A. D., .14) per second for the control series. This shows that there is a reduction in brightness under conditions of kinaesthetic strain quite similar to that resulting from auditory stimulation. In the light of these data, therefore, it would seem plausible that in the case of D the effects produced by muscular tension, which itself was probably a result of the auditory stimulation, in some way crept in to overcome the possible increases in brightness which auditory stimulation might have produced directly.

This theory of the possible cause of the opposing results for D does not impeach the evidence offered by the measurements, namely, that for this observer the auditory stimulation produced an appreciable dimming of the subjective brightness. That fact is evident and indisputable. But the theory is offered as a possible way of uniting these opposing results and of reconciling them to a large body of evidence in the field of synaesthesia and in the literature on inter-sensory effects. It is not intended to imply a denial that there are certain physiological and psychological mechanisms which operate quite differently in these two types of observers to produce the brightening for the one and the dimming for the other. It is obvious that the two types are responding quite differently in the two cases. For both the response is a total reaction, and simply pointing out possible factors which might supply a differential mechanism in the one does not discredit the very evident fact that the reactions are diametrically opposite. The real problem is that of determing what factors would cause kinaesthesis to predominate in the negative types and not in those for whom auditory stimulation produces a brightening. The details of this problem will be taken up more at length later on.

Since this contradictory evidence is at variance with a considerable amount of evidence from the literature on synaesthesia and from the investigations on non-synaesthetic observers cited above all of which indicate that stimulation with sounds of high pitch invariably results in a heightening of subjective brightness, it became evident that more specific evidence with respect to the general prevalence of brightness enhancement with such sounds must be obtained. To the end, therefore, of determining whether this effect of a lowered fusion threshold could be found for other individuals a number of other experienced observers were trained to make fusion threshold determinations. The results for the entire group of observers, including the original three, using a light of 687 mu mus, at an intensity of 25 photons, are given below. The tone, as before, was of 2000 vibrations per second and of moderate intensity.

	Without Sound		With Sound	
	Average (n/sec.)	A. D.	Average (n/sec.)	A. D.
Observer B	24.8	.15	25.2	.1
Observer C	25.2	.25	26	.34
Observer D	22.4	.1	21.6	.17
Observer M	20.9	.14	20.5	.17
Observer S	24	.12	25.4	.25
Observer W	25	.21	26.3	.31
Observer Wh	24.5	.44	27.2	.47

These data show that five of the total number of seven reacted positively, i. e., with an increase in brightness upon the introduction of the auditory stimulation, while two reacted negatively, i. e., with a dimming of subjective brightness. Two other observers were used at one time or another, but no figures are given for them, since the results obtained were not consistent enough to be significant. Judging from the large mean variation of their judgments, this was due most likely to the fact that they were unable to attain a sufficient degree of precession to permit small differences to show up during the short time they had to practice. Introspective reports from these two observers indicated that the introduction of the sound produced very definite alterations in the character of the experience for them as well as for the other observers.

A check experiment to determine whether the induction of sound was capable of producing flicker in a previously fused field was carried out on a number of observers. It should follow, if the sound has the effect of raising the fusion point, that by adjustment of the episcotister carefully to a point just barely above the fusion point without auditory stimulation, the induction of sound as a stimulus should cause flicker to appear. And, in the opposite direction, it should be possible with auditory stimulation to produce fusion at a rate which without auditory stimulation flickered slightly in the case of those observers for whom auditory stimulation had the effect of lowering the rate necessary for fusion. The results of these tests were positive for both types of observers, the positively reacting individuals reporting the appearance of flicker in a previously fused field with auditory stimulation and the negatively reacting individuals reporting fusion where there had previously been a slight flicker. The conditions under which the positively reacting individuals observed were somewhat complicated, however, by the fact that an adaptation effect, involving the momentary appearance of flicker immediately upon turning the eye toward the field, might have been confused with flicker resulting from the auditory stimulation itself.

There were a number of indications that the temporal aspects of the problem are of importance. D reported a momentary brightening of visual experience together with more pronounced flicker, both of which immediately gave way to the dimming effect and lowered fusion thresholds which measurements show to be characteristic of D's response. However, if such an enhancement did actually take place for this observer as a result of auditory stimulation, it was so fleeting as not to permit of measurement. It is altogether probable that this transitory character of the enhancement was due to some process of adaption rather than to the sound.

Evidences of persistence of effect due to the auditory stimulation were noted in six observers. For a period of several minutes after the cessation of the auditory stimulation fusion point determinations showed the effects of the stimulation. For all of the positively reacting subjects this effect manifested itself in the form of a sort of hypersensitivity of response, so that the field remained apparently brighter. In a similar fashion, it was noticed that there was a like persistence of the dimming effect after the sound was turned off in the case of the negative observers. While no very systematic or comprehensive measurements of these effects were taken, the following measurements, taken with a visual field of comparatively low intensity, will serve to indicate the character of these persistent effects: without sound, 17.4; with sound, 15.8; and approximately two or three minutes after the cessation of the sound, 16.5. The effects in the case of those who reacted with an increased fusion threshold were quite similar with respect to persistence. The persistence of these effects, particularly regarding the feeling side of the experience, was quite noticeable to the different individuals observing. In the case of the writer, the peculiar keyed-up feeling which accompanied the continued stimulation with the high pitched sound definitely endured, leaving a feeling of nervousness and of a high degree of excitability.

Interesting and significant examples of the notorious inaccuracies involved in purely subjective estimations of visual brightness were observed. In several instances, and consistently for one observer, the subject reported with a high degree of certainty that there was an apparent brightening of the visual field, while the fusion threshold judgments taken at the same time indicated that there was actually a dimming of the visual experience.

2. Qualitative

The introspective reports of all observers show that definite qualitative changes took place in the apparent character of the visual field with auditory stimulation. While these observations show considerable variation in the type of response from one individual to another, there are certain aspects of the experience that are common to all. We shall consider some of those characteristics, first, as they appear in the positively responding observers, and then as they are found in the negatively reacting individuals.

Wh describes the sound, although fairly intense, as not at all unpleasant when it is introduced into the stimulus situation. Indeed, up until the very last part of the experiment the experience was described as decidedly pleasant. After prolonged stimulation the sound began to pall on the observer. The effective toning of the experience was a particularly prominent aspect of the experience. Wh's further report on the feeling quality of the experience under auditory stimulation describes it as characterized by a "dynamic quality, a feeling of being keyed up". "There was a feeling of innervation and of buoyancy, a state almost bordering on euphoria." Wh was the only observer who reported the auditory stimulation as definitedly pleasant, most of the observers finding it extremely disagreeable, while several were relatively indifferent to it.

With respect to the appearance of the visual field under concomitant auditory stimulation, Wh reported that, although at first the field appeared somewhat blurry and indistinct, "the disc settled down and became brighter and more stable" during the course of the observation. The hazy and indistinct boundaries of the field gave way to a clear-cut contour. "The disc at the same time became flatter and began to lose its original quality of tridimensionality. The flickering became sharper than it had been with sound, and the demarcations between one phase and the next became more precise--clearer in the sense of one phase passing more quickly into the next. There was a more differentiated, cleaner-cut change instead of the previous blurriness." The visual disc appeared brighter and more yellow and the dark field surrounding the colored disc seemed even more intense with auditory stimulation, according to this observer.

Introspections similar to the above were given by C and by Wi.[6] The former reports that "the flicker changed with the sound into a more definite and clear-cut sort of flicker. It was not so blurred and smeary." According to Wi "the field seemed brighter and more lively with sound." "The feeling with sound was more stimulating." This observer also mentions a heightening of the feeling tone which accompanies auditory stimulation as being particularly prominent. Wi also volunteered the information that he had a feeling that his judgments with sound should be more consistent than without. The preliminary measurements that were taken in his case, however, indicate that the opposite was actually the case.

The report of S is significant. In describing his subjective reaction when the auditory stimulation was introduced, he said that it seemed as if his whole perceptual system began to operate "at a higher functional level". This apparent toning-up of the perceptual processes in turn gave rise to a feeling that there "should be a facilitation and enhancement of the brightness response". This observer did not consider the sound to be unpleasant or irritating. With respect to the apparent changes in the visual field, S reported a shrinking of the visual field immediately after the introduction of the sound.

W observed, and the reports of the other positively reacting observers would indicate a general agreement with his observation, that the addition of auditory stimulation resulted in an increased liveliness within the visual field. There seemed to be a sort of internal strife within the visual field which could not be easily resolved. The qualitative character of the flicker continuum seemed to change just barely below the fusion point to a kind of flicker that was not observed in series made without auditory stimulation. The character of this barely subliminal flicker is difficult to describe, but it may somewhat inadequately be characterized as an appearance of instability possessing a peculiarly persistent quality which almost forced itself on the attention of the observer. This type of experience seems definitely different from that reported by the negatively responding observers, since it will be noticed that for them there was a blurring and blotting out of what had previously been distinctly perceptible flicker.

When we turn to the two observers for whom auditory stimulation resulted in a dimming of the visual field, we find different effects noticed. D observed that the sound caused a noticeable dimming of the visual field, together with a decrease in the distinctness of the flicker.[7] Instead of the increased liveliness of the visual field reported generally by the above observers, there was a distinct dampening of movement within the visual field. D also ascribed a fleeting desaturated and washed-out quality to the visual field immediately after the sound was turned on.

The report of M agrees with D's in that auditory stimulation seemed to result in a finer and more indefinite flicker and a more homogeneous field. Contrary to D, however, she consistently reported an apparent brightening of the visual field with sound. This was but one of the several instances we have referred to in which the observer's report of the experience and the measurements of brightness did not agree. Even when this observer was aware that the auditory stimulation had lowered her fusion threshold, she insisted that the field appeared to be brighter.

While the above descriptions indicate in some measure the complexity of and the consequent wide variation in response to this type of situation, certain common features may be pointed within each of the two main groups which have been indicated by the quantitative data. While the characteristic responses of these two groups are not mutually exclusive, it is significant in accounting for the wide discrepancy between the results, to point out of a highly complicated subjective response certain characteristic attitudinal differences that may operate to differentiate the response of one individual markedly from that of another.

Probably the most prominent character of the positively reacting individual's response was that of a general stimulation of the entire perceptual system as a result of auditory stimulation. The induced tone seemed to produce a certain toning up of the perceptual processes. Wh's description of this experience as having a "dynamic quality", as resulting in "a feeling of being keyed-up", and of giving rise to a feeling of innervation and buoyancy, is an example of this. The observation of S that there was an apparent change in perceptual experience "to a higher level" is another case of this sort.

As we have suggested previously, no very definite division can be made with respect to the pleasantness or unpleasantness of the experience, since only one of the observers described the experience as definitely pleasant. It is significant, however, that most of those in the positively reacting group did not consider the auditory stimulation to be unpleasant. On the contrary, both of those who reacted with a lowered fusion threshold considered the auditory stimulation quite disagreeable and unpleasant.

Instead of a heightened functioning of the perceptual system and a more sharply differentiated response, as in the case of those observers who responded positively, there was a distinct dulling of the visual response and a consequent loss of the capacity to make finer differentiations in judgment with respect to the fusion point on the part of the two negatively reacting individuals. For them flicker lost its distinctness and became broader, coarser, and less clear; there was a blurring and blotting out of what had previously been clearly perceptible flicker.

One of the most striking and significant characteristics of the negatively responding observers is seen in the antagonistic attitude which they seem to adopt with respect to the secondary stimulation. There appears to be an attitude of distinct hostility towards and a tendency to fight off the intruding stimulus, as if they felt that it interfered with their perception of the visual field. They apparently regarded it as something disagreeable and distracting, and not, as the positively reacting subjects did, as a factor contributing to a more successful functioning of the general perceptual system.

IV. THEORETICAL CONSIDERATIONS

1. Criticism of Associational and Attentional Theories of Inter-Sensory Effects

Even the most casual observation reveals to us the highly unified character of experience. We observe that experience in general and sensory experience in particular are not aggregations of discrete elements, but that the predominant character of experience is that of organized wholeness. Sensory experience, for example, is never merely the addition of sensations of one modality to those of other modalities. On the other hand, the reverse process takes place; the particular phases of sensory experience emerge as aspects standing out from an unanalysed background. This highly unified nature of experience is to be observed in every aspect of mental life and at every level from the dimmest and vaguest awarenesses and feelings to those of the most complex mental states.

Yet at the same time the unitary character of sensory experience is obvious. It must be recognized that any analysis of experience has to take account of the fact that experience exhibits certain aspects which appear qualitatively different from one another. The quality of experience elicited by a certain type of physical stimulus is recognized as different from that called forth by another type of physical stimulus. Furthermore, there are certain structures and processes within the body which afford the organic basis for the production of these different qualities of experience.

By the time Aristotle wrote his De Sensu, sensory theory had recognized this division of sensory experience into the five fundamental types, and a certain amount of progress had been made toward assigning organs as seats of the separate sensations, although knowledge along this latter line was limited and meager. Aristotle's famous treatise on the senses, containing a definite enunciation of the doctrine of the five senses, marks the beginning of a long tradition in sensory theory, during which time there has been practically no change in the fundamental doctrine.

While the doctrine of the five senses represents an accurate analysis of the most obvious aspects of sensory experience, the course of historical development has shown, however, that the abstract nature of the sensory modes has been lost sight of, and, instead of being thought of as the products of an analysis of experience, the five senses have been taken in an absolute sense and used as independently real elements of sensation. The distinction between sensory experience as it really exists and sensory experience as a congeries of the several components which analysis gives was forgotten. By assuming that the process of analysis was reversible in a process of synthesis an account of the total sensory experience in terms of its parts was justified. The inadequacies of this position did not become apparent until it was necessary to account for certain close relationships between the several senses.

Consequently, when empirical evidence from the field of synaesthesia and from reports of cases in which definite inter-sensory effects were found in normal observers, it became evident that some theoretical provision beyond that supplied by simple analysis into its partite form was demanded. This was done by patching up the old partite theory of sensory experience. In order to do this two assumptions were made: first, that the analyzed elements of sensory experience could be synthetized into a new total experience, and second, that some external agency existed which operated to accomplish this synthesis. The first assumption was common to the two main theories advanced, while efforts to supply the agency of synthesis followed the two main lines which were traditionally taken in an attempt to account for mental unity, namely, through the postulation of associational or attentional concepts.[8]

According to the conventional theory of inter-sensory effects, particularly such outstnading ones as we have in synaesthesia, the calling forth of an effect in one field as a result of stimulation in another, such as, for example, we have in visual experience, is to be accounted for on the basis of a chance association which has been stamped in sometime during the life of the individual. In other words, there is a "primary" sensation - in the preceding example, the tone - to which is attached, in purely chance fashion, the "secondary" sensation, i. e., the change in visual experience. There are, however, a number of serious objections to be advanced against this theory. In the first place, the assumption of chance as the selective agency in the formation of these inter-sensory connections is absolutely untenable in view of the regularity of many correlations between visual and auditory phenomena. Second, there is a continuum of stimuli in another sensory field. As we have pointed out specifically in one instance and as has been frequently reported in the literature, changes in pitch give rise to concomitant changes in brightness throughout two correlated continuua. Third, as other investigators have pointed out, the synaesthetic experience is a unified reaction. The colors which frequently accompany sound are integral parts of the hearing process, and it would be impossible for the synaesthetic person to hear the tones without the visual imagery. Fourth, the assumption of a chance agency gives no adequate explanation for the meaningful character of synaesthetic experience.

The effort to account for inter-sensory effects in terms of the primary sensory experience is produced because the secondary stimulus has caused a greater degree of attention to operate in the perception of the primary stimulus pattern. Thus there may be a brightening of the visual field when a particular sound is heard because, it is held, the sound causes the visual field to be observed with a greater degree of attention.[9] Like the theory of association, the attention theory fails to do justice to the unified character of sensory experience, but the main objection to this theory is on systematic grounds. Attention is an external agency, an entity entirely apart from and outside of the processes actually involved in such experience, which has been made necessary through the assumption of elementary sensations.

If, on the other hand, the objectionable systematic implications of this term are avoided by taking the term "attention" in its common usage to denote the particular set of circumstances which operate in a given situation in which inter-sensory effects take place, the concept loses all meaning. No great advantage is gained through the giving of a name to a set of conditions which are responsible for the production of these effects is.

2. A Genetic Theory of Sensory Development

It is evident, therefore, that no theory which regards sensory experience in an elementaristic fashion and fails to provide a sufficient theoretical account of the close relationships which exist between the particular senses can be considered adequate as an account of the nature of sensory experience. Instead of theories which assume separate and discrete senses, we must have a theory which emphasizes the unified character of the total sensory field. To this end the theory has been advanced[10] that the several senses have developed through a process or individuation as emergents from an original undifferentiated common source, a diffuse general sense. It is supposed that the five particular senses have developed out of a primitive sort of common sense, as specializations and differentiations during the course of genetic development.

On this view, synaesthesia is merely a pronounced expression of the genetic unity of the sense. Synaesthetic persons are simply individuals in whom this process of differentiation of the several senses from one another has not proceeded as far as in the average person, so that stimulation of one sense produces pronounced effects in other sensory fields simply because the two senses are still closely connected. For non-synaesthetic subjects such effects are much less pronounced because the senses have developed a greater independence of one another than in synaesthetics.

As we have pointed out, there is no essential difference between the inter-sensory influences of synaesthetic subjects and the inter-sensory effects found in normal observers. The degree to which such effects exist would vary greatly among individuals, ranging in extent from those individuals in whom there is little evidence of such effects to those synaesthetic persons in whom such experiences are much more pronounced and for whom they comprise a more vital part of the individual's sensory experience.

Some indirect evidence in favor of the genetic theory is obtained from reports of cases in which mescal intoxication produced temporary synaesthesia. In such cases it is presumed that the action of mescal results in the breaking down of the finer differentiations within the sensory field, so that sensory experience temporarily regresses to a lower level. Synaesthetic phenomena occur under such conditions because at these lower levels the inter-sensory connections are much closer, since they are nearer to the primitive undifferentated sensory experience. In such states the sensorium is no longer so completely marked off into compartments as in normal states, leaving the response less differentiated.

3. A Theory of Types of Response

While it is to be expected that definite differences would be found in the degree to which inter-sensory phenomena are present in different individuals, because of the fact that the process of individuation would not proceed as far in one individual as in another, the problem becomes definitely more complicated and difficult when we consider the evidence pointing to a brightening effect in the case of one observer and a dimming effect in the case of another. The present experimental evidence shows quite clearly that there are those who react with a reduction of the fusion point as well as those who react in the opposite direction, but the reason for this does not at first sight appear to be clear.

While the existence of a dimming effect when auditory stimulation of high frequency is introduced in the case of some observers is another piece of evidence in favor of a genetic theory of sensory development, the implications of this fact must be critically examined because of their significance for theories of synaesthesia and sensation in general. It is disturbing largely because it upsets one of the correlations in the field of synaesthesia, namely, that of pitch with brightness. There is a great deal of evidence pointing to the fact that high pitches invariably elicit an increased brightness in visual experience, but the results of the present experiment cast grave doubt on the universal validity of this correlation.

As we have pointed out in Section II, there is the possibility of reconciling these negative cases with the known facts with respect to this point in the literature on synaesthesia by the assumption that other factors are aroused in this type of observer, which operate to overwhelm the effects of brightening set up by the auditory stimulation directly. It is entirely possible that kinaesthetic strain, usually interpreted synaesthetically as a dimming, which is set up by the experimental conditions, become so pronounced in these observers as to completely overshadow any brightening which might result from auditory stimulation directly.

In any event, however, the indication of a possible factor that may enter into the situation does not meet the question as to how it comes about that, although the stimulus situation for both types of observers was the same, diametrically opposite reactions took place in the two types. In ascribing the different reaction to the dominance of the response from kinaesthetic strain, we have simply pushed the question back one step further, and the main problem, that of determining what it is that causes the kinaesthetic factors to predominate in the one and not in the other, still remains.

Any consideration of the nature of the fusion phenomenon precludes the view that what we are dealing with in such cases is a simple sensory process operating at a low level. While the questions involved in a theoretical consideration of the fusion process are somewhat beyond the scope of this article, an examination of the conditions under which brightness measurements take place, showing the complexity of the reaction, may lend support to the view that these differences may be due to typological differences among observers.

In phenomena involving the fusion of intermittent light impulses for the measurement of subjective brightness, we have a psychophysical relationship involving, on the one hand, a definite measurable physical stimulus and, on the other, the subjective reaction to that stimulus presentation. The latter may for convenience be divided into peripheral, i. e., retinal, processes and central processes. Changes in the intensity of the stimulus field give rise to concomitant changes in the subjective response, provided the stimulus is above a certain value, satisfies certain temporal requirements, and meets other psychological and physiological requirements. This response bears, under hypothetically constant conditions, a definite relation to the intensity of the physical stimulus. Since under the conditions of the present experiment the physical stimulus conditions were held constant, the causes for the change in rate necessary to produce fusion after auditory stimulation was initiated must have been on the subjective side. Furthermore, it is possible to rule out retinal factors as possible determining factors, since it would be impossible for auditory stimulation to influence the visual responce through any channels other than central ones. The critical frequency of fusion, the measure of brightness, is thus the product, at least to a very significant degree, of central determinants.

These deductions with respect to the central determination of measured brightness, taken together with the evidences of significant differences in subjective attitudes, as we have noted in Section II, add considerably to the plausability of the theory that the brightness response under the influence of auditory stimulation varies in direction according to the type of individual. Significant attitudinal differences make it seem possible that such factors operate so as to produce changes in opposite directions in the centrally determined processes. Certain it is, at any rate, that the conception of central determination gives a greater flexibility to our notions concerning such perceptual processes.

Results of work by Jaensch and his associates, who have reported instances in which sensory experience varies according to the two fundamental personality types posited by the eidetic theorists, increase the plausibility of the results bearing on the importance of types of observers indicated in this investigation.

4. Suggestions for Further Research

Further experimentation designed to check specifically the present evidence with respect to two fundamental classes of reaction types through the testing of certain factors that might enter in to give a false appearance of two classes should be carried out before this dichotomy is finally accepted. Besides the extension of this research to greater numbers of experienced observers, similar experiments should be undertaken with groups of naive observers in an effort to ascertain the degree to which laboratory sophistication may influence results, and also with as many observers highly trained in making critical frequency of fusion judgments as possible, to check up on the possible influences of indirect cues in the making of fusion point determinations. There is also a great deal of work to be done on the other aspects of the problem--the effect of variation of the hue of the visual field, the effects of variation of pitch and intensity, etc. These parallel researches would serve as significant supplements to the present work.

V. CONCLUSIONS

1. Quantitative data for seven observers, showing measurable changes in subjective brightness of a visual field of a given intensity when auditory stimulation is induced, are presented. This is interpreted as evidence of the genetic unity of the senses.

2. These data show that changes do not take place in the same direction for all individuals. For two of the observers the induction of auditory stimulation resulted in a lowering of the critical frequency of fusion, indicating decreased subjective brightness. For the other five subjects there were increases in brightness.

3. Since it is evident that for at least some observers auditory stimulation results in decreased subjective brightness, the results of previous research on the nature of inter-sensory effects, which suggest that auditory stimulation uniformly gives rise to brightness increases, are challenged. There is the possibility that other synaesthetic factors, which operate to darken the visual field, such as kinaesthetic strain, may be aroused in the one group of observers to such an extent that they overwhelm any possible brightness increases which might result directly from the auditory stimulation. However, this does not explain the more ultimate causes for such a

response being called forth in one individual and not in another.

4. The possibility that there may be typological differences among individuals, which determine the direction in which the brightness changes take place, is discussed. Observed differences in subjective attitude among the observers, which may determine the direction of change in the central processes involved in visual brightness experiences, lend some support to this theory.

5. The fact that auditory stimulation brings about changes in the critical frequency of fusion point to a central origin of visual flicker.

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APPENDIX

FOOTNOTES

1. The writer was unable to obtain access to the greater part of Lasareff's writings and was forced therefore to rely on the short account presented in the latter's Jonentheorie der Reizung and on indirect references to this work to be found elsewhere in the literature.

2. Newhall, S. M., The Effects of Attention on the Intensity of Cutaneous Pressure and on Visual Brightness, Archives of Psychology, 61, 1923, p. 55

3. Op. cit., p. 60

4. See Kravkov, S. W., Über die Abhängigkeit der Sehschärfe vom Schallreize, Graefes Archiv für Ophthalmologie, 124, 1930, p. 336 f, for an account of the temporal duration of auditory effects.

5. This information was communicated to the writer by Dr. T. D. Cutsforth.

6. Wi is one of the observers for whom we have presented no quantitative data.

7. It will be remembered that in the section on the quantitative aspects of the problem it was mentioned that D reported a momentary brightening effect. As we have pointed out this was probably due to the adaptation effects and is not to be confused with the persistent brightness effects obtained for the other observers.

8. We pass over a theory which antedated these two views and which as persisted in spite of its inadequacies until as late as 1923, when it was advanced in modernized version by Lasareff. This theory involves the postulation of some physiological mechanism which operates in some way so that physiological processes in one sensory field operate to produce effects in another. Lasareff's ionic theory, for example, postulated a flow of neural energy from the path of one sense over into the neural pathways of another. Such attempts to give a physiological account of intersensory phenomena involve all of the fallacies of premature efforts to provide physiological mechanisms to account for psychological phenomena which are little understood. It would seem advisable to proceed further with investigations of the psychological phenomena involved before attempts are made to provide physiological bases for these phenomena.

9. S. M. Newhall, The Effects of Attention on the Intensity of Cutaneous Pressure and on Visual Brightness, Archives of Psychology, 61, 1923, p. 4, gives this interpretation when he says, "It is suggested that the clicks may contribute to a higher degree of attention, and that to the latter may be due the greater number of stimuli judged super-threshold and the greater brightness, when the clicks are used."

10. This theory has been suggested by Wheeler and Cutsforth, An Organismic Theory of Synaesthesia, in R. H. Wheeler, Readings in Psychology, pp. 358-359, and Karl Zietz, Gegenseitige Beeinflussung von Farb- und Tonerlebnissen, Zeitschrift für Psychologie, 105, 1928, 226-249, has elaborated this viewpoint.

DATA

Observer: D

7.5 photons:

Without Sound		With Sound: 2000/sec.	
1.03	1.06	.97	.99
1.01	1.06	1.01	.97
1.06	1.07	.98	.97
1.03	1.06	.97	.97
1.07	1.04	.99	.96
Average	1.05	Average	.98
A. D.	.017	A. D.	.012
n/sec.	18.5	n/sec.	17.2
A. D.	.31	A. D.	.21

25 photons:

Without Sound		With Sound: 2000/sec.	
1.27	1.27	1.21	1.24
1.28	1.27	1.20	1.23
1.27	1.26	1.21	1.24
1.27	1.28	1.23	1.23
1.28	1.25	1.23	1.24
Average	1.27	Average	1.23
A. D.	.006	A. D.	.01
n/sec.	22.4	n/sec.	21.6
A. D.	.1	A. D.	.17

50 photons:

Without Sound		With Sound: 2000/sec.	
1.51	1.52	1.48	1.39
1.52	1.48	1.48	1.43
1.48	1.49	1.47	1.44
1.48	1.51	1.43	1.43
1.51	1.50	1.43	1.44

Average	1.50	Average	1.44
A. D.	.014	A. D.	.02
n/sec.	26.7	n/sec.	25.4
A. D.	.24	A. D.	.36

Observer: W

7.5 photons:

Without Sound		With Sound: 2000/sec.	
1.15	1.12	1.18	1.19
1.15	1.10	1.16	1.18
1.18	1.13	1.18	1.16
1.16	1.14	1.17	1.11
1.12	1.14	1.19	1.18
1.13	1.12	1.17	1.16
1.14	1.13	1.16	1.18
1.16	1.13	1.18	1.16
1.16	1.11	1.17	1.16
1.12	1.15	1.19	1.16
Average	1.14	Average	1.17
A. D.	.016	A. D.	.012
n/sec.	20	n/sec.	20.6
A. D.	.28	A. D.	.21

25 photons:

Without Sound		With Sound: 2000/sec.	
1.42	1.45	1.50	1.48
1.37	1.43	1.46	1.49
1.40	1.42	1.50	1.47
1.41	1.43	1.53	1.52
1.42	1.42	1.47	1.49
1.42	1.40	1.47	1.54
1.42	1.42	1.50	1.53
1.44	1.43	1.49	1.51
1.44	1.43	1.46	1.49
1.40	1.44	1.50	1.49

Average	1.42	Average	1.49
A. D.	.012	A. D.	.018
n/sec.	25	n/sec.	26.3
A. D.	.21	A. D.	.31

50 photons:

Without Sound		With Sound:2000/sec.	
1.55	1.55	1.65	1.58
1.57	1.58	1.62	1.61
1.57	1.56	1.68	1.60
1.60	1.54	1.65	1.63
1.57	1.57	1.60	1.66
1.58	1.57	1.67	1.62
1.58	1.56	1.62	1.62
1.57	1.56	1.65	1.62
1.57	1.57	1.63	1.61
1.58	1.55	1.60	1.62
Average	1.57	Average	1.63
A. D.	.009	A. D.	.021
n/sec.	27.7	n/sec.	28.8
A. D.	.16	A. D.	.37

Observer: Wh

7.5 photons:

Without Sound		With Sound:2000/sec.	
1.05	1.01	1.04	1.08
1.00	1.03	1.03	1.11
1.97	1.00	1.03	1.12
.97	1.01	1.08	1.04
1.00	1.01	1.12	1.05
		1.11	1.02
Average	1.00	Average	1.07
A. D.	.017	A. D.	.034

n/sec.	17.6		n/sec.	18.8
A. D.	.30		A. D.	.58

25 photons:

Without Sound			With Sound: 2000/sec.	
1.37	1.37		1.51	1.47
1.45	1.37		1.54	1.49
1.43	1.38		1.56	1.56
1.41	1.37		1.54	1.57
1.37	1.39		1.56	1.56
1.37	1.37		1.55	1.57
1.38	1.42		1.57	1.56
1.34	1.36		1.51	1.55
1.37	1.43		1.50	1.52
			1.48	1.57
Average	1.39		Average	1.54
A. D.	.025		A. D.	.027
n/sec.	24.5		n/sec.	27.2
A. D.	.44		A. D.	.47

50 photons:

Without Sound			With Sound: 2000/sec.	
1.85	1.72		1.90	2.05
1.82	1.87		2.02	1.85
1.86	1.74		1.85	2.05
1.87	1.85		1.97	2.11
1.75	1.76		2.07	2.05
Average	1.81		Average	1.99
A. D.	.053		A. D.	.08
n/sec.	32.1		n/sec.	35.3
A. D.	.74		A. D.	1.42

Observer: B

25 photons:

Without Sound			With Sound: 2000/sec.	
1.41			1.43	

1.41		1.43	
1.40		1.44	
1.42		1.44	
1.43		1.42	
Average	1.41	Average	1.43
A. D.	.008	A. D.	.006
n/sec.	24.8	n/sec.	25.2
A. D.	.15	A. D.	.1

Observer: C

25 photons:

Without Sound		With Sound: 2000/sec.	
1.45	1.42	1.48	1.46
1.43	1.45	1.45	1.47
1.46	1.46	1.45	1.45
1.43	1.43	1.49	1.46
1.40	1.42	1.50	1.47
Average	1.43	Average	1.47
A. D.	.015	A. D.	.019
n/sec.	25.2	n/sec.	26
A. D.	.25	A. D.	.34

Observer: M

25 photons:

Without Sound		With Sound: 2000/sec.	
1.20		1.16	
1.19		1.18	
1.19		1.18	
1.17		1.15	
1.18		1.17	
Average	1.19	Average	1.17
A. D.	.008	A. D.	.01
n/sec.	20.9	n/sec.	20.5
A. D.	.14	A. D.	.17

Observer: S

25 protons:

Without Sound		With Sound: 2000/sec.	
1.36	1.36	1.39	1.44
1.36	1.37	1.42	1.45
1.37	1.36	1.44	1.46
1.38	1.35	1.44	1.46
1.37	1.36	1.43	1.47
Average	1.36	Average	1.44
A. D.	.007	A. D.	.015
n/sec.	24	n/sec.	25.4
A. D.	.12	A. D.	.25

N. B. It will be noted that the individual readings are given only in terms of the volts registered on the tachometer voltmeter. Translation of the average voltage into stimulations per second was made from a curve which indicated the relationship between voltage and rate of revolution.