Journal of
Experimental Psychology

VOL. 34, NO. 2 APRIL, 1944

THE EXPERIMENTAL DEVELOPMENT OF COLOR-TONE SYNESTHESIA

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The quality which has traditionally differentiated the psychologist from the unspoiled layman is his persistent endeavor to dissect experience. The classical psychology has commonly taken for granted that experience is an incidental or secondary product of varying combinations of discrete and independent sensations. On the other hand, the more modern, instrumental view tends increasingly to interpret all sensations and perceptions as incidental to the overall process of organic adjustment or achievement, and is inclined to suspect that all of the qualities and meanings of sensations and perceptions, the very origin, maintenance, and mode of discrimination of sensory components, depend in the long run upon how effectively they guide the total process of integration of the whole organism.

The immediate world of the child is evidently quite unitary and undivided. Neither the child nor the animal is adept at analyzing his experience. On the other hand, the more sophisticated psychologist tends characteristically to departmentalize and classify his impressions of his environment. The first experimental psychologist was perchance some primordial boy who lay idly on his back and wondered at the marvelous changes which could be wrought in Nature, simply by opening and closing his eyes. As psychologists have done ever since, he perhaps conjectured that the complex experience which came and went as his eyelids moved was furnished solely by his eyes—in other words, the *erreur de préjuge*. He was probably quite naively certain that the peculiar shivery quality of the sight of white snow, for instance, was altogether optical, and ignored the possibility that many of its qualities were originally derived from his other senses. The boy saw the snow as cold and wet because very likely he had once felt that it was cold and wet at the

same time that he saw that it was white. Also, he now saw it at a distance because when formerly he saw and felt it, he had also reached or walked to it, and thus added kinesthetic data to his perceptual composite. If one hears the sound of wheels crunching the cold snow outside, he may be unable to restrain a shiver, even if he is sitting by the fireside, especially if at some time or other he has happened to hear this peculiar squealing noise when he also suffered with the cold and probably struggled to reach warmth. All of these transfer effects are probably dependent, not only upon simultaneity of different stimuli, but also upon their utilization or involvement in a purposive quest for some sort of end, in other words, in an operant response. Recent developments in psychology are challenging us to consider the hypothesis that all our observations of the world are incidental to what we are doing at the time, to our larger and longer program of adjustment or goal achievement, such as trying to obtain food or shelter, and through them, perhaps, survival.

Linkage of the senses, so that stimuli normally reacted to by only one kind of receptor may produce experiences or reactions which are supposedly specific to another sense, is commonly known as synesthesia. It is evidently involved in all perception to a much greater extent than is generally realized. As a matter of fact, if perception is regarded as a synthesis of more elementary impressions, synesthesia may be considered as practically identical with perception. Synesthetic processes may accomplish the basic functional integration of sensory data, not only between the different senses, as usually assumed, but also within a single sense, such as hearing or seeing. For instance, a photograph of a landscape on a book page gives the effect of seeing far distance, even though the accommodation of the crystalline lens and the convergence of the eyes, which are normally the principal means of perceiving distance, are adjusted for close-up rather than for far vision. In spite of this interference, perception of distance in a picture is nevertheless achieved vicariously because of a preponderance of other associated factors supplied by the photograph, and which usually accompany the normal ocular adjustment for seeing distance, such as differences in sizes of the retinal images of far and near objects, perspective, contrast, brilliancy, superposition, etc. The depth effect in a picture is improved if one eye is closed so as to get rid of contradictory evidence from that eye indicating that the picture is a flat surface.

Errors in perception of distances when one first wears a new pair of glasses are probably a result of an influence which may be termed synesthetic. The changed refraction of the new lens imposes a different ocular accommodation from that formerly used for focusing a given object, and synesthetically perverts the evidence of the other

factors, which results in a misjudgment of distance. Errors in spatial orientation when using the pseudophone or pseudoscope might also be classed as synesthetic, since in each instance sensory cues (auditory, visual, and kinesthetic) are working in conflict with each other; the influence of any one of these on the others might very well be interpreted as synesthetic. Ventriloquism is evidentally a synesthetic phenomenon too, since both the source and quality of the sounds are misinterpreted because of more influential visual evidence supplied by the puppet but concealed by the ventriloquist.

In G. M. Stratton's famous experiment on inverted vision (6), the interference between visual and auditory cues in locating objects in space is evidence of a synesthetic influence of each on the other, since the effect of sound was to change visual perceptions. The fact that this interference was afterwards overcome is evidence that in the long run perceptions are subsidiary to the total process of adjustment.

In these instances, as always, temporary conflict between ordinarily integrated factors is necessary to demonstrate their normal coördination and mutual support. Such coöperation between and within the senses is obviously indispensable to the organism in attaining its objectives, and serious interferences between them may result in organic disaster. As long as sensory data coöperatively contribute to organic adjustment their existence as elements is ignored. Recognition occurs only if and when they are removed, or else contradict the meaning of each other and thereby produce intra-organic conflict.

A very interesting and obviously spontaneous development of synesthesia recently came to the attention of the writer. For some years an auto driver had frequently passed a certain street crossing where a whistle was sounded automatically whenever the lights changed for *stop* and *go*. It happened later that the whistle was discontinued, although the lights continued to change as usual. A few days after this discontinuance, when a friend remarked to the driver that the whistle no longer sounded, he vigorously denied it and claimed he had heard the whistle that morning. On the next trip to the crossing, in spite of counter suggestions recently received, the driver reported a distinct hallucination of the whistle. This effect gradually diminished when further investigation proved that the whistle no longer sounded. Even the pitch of the tonal image, or hallucination, as reported by the driver when the lights changed, was identified by him on an adjustable whistle and later verified as approximately correct by comparison with the actual whistle. Other tests made away from the vicinity of the lights indicated that in a different setting the driver apparently could not so exactly reproduce this tone from memory.

In another instance reported to the writer a higher-toned whistle was normally sounded when the lights changed to red for *stop* and a lower tone accompanied the *go*. Few drivers noticed that there was a difference in the tones, or even that a whistle sounded at all, until the wires controlling the whistles were accidentally crossed by a repairman, so that the usual combinations of color and tone were reversed. The result was general confusion and a collision at the crossing.

As did the deceptive instances reported, the standard psychological illusions generally arise in a conflict situation and are usually temporary. They are often overcome by a process of counter-conditioning, in which new meanings and values are afterwards ascribed to the contributory sensory cues as a consequence of a general reorganization of the activities which they mediate, and finally because of influence of the overall process of organic adjustment which is itself mediated in turn by these activities.

Problem

Consideration of reports of phenomena, such as those described above, resulted in the formation of a general hypothesis of synesthesia: namely, that synesthetic effects may be the result of an association or combination of sensori-motor activities, if and when they are functionally involved in a larger and longer process of organic adjustment or goal achievement, or in other words if they are derived from a dynamic whole. This hypothesis seemed to offer a somewhat novel interpretation of synesthesia, and also suggested a new and untried method of producing it experimentally. Also this new experimental approach seemed to provide a possible medium for testing, or at least application of, the general hypothesis that all sensory experience, including synesthetic, is instrumentally determined.

We therefore cast about for a specific experimental situation which might provide the basic conditions for such a test: namely, first, that different receptors of the subjects would be simultaneously stimulated by appropriate controlled stimuli; secondly, that the sensory functions involved must normally work together coöperatively in achieving a psychological end or goal, so that this end becomes the chief object of attention rather than the sensations themselves; and, thirdly, that an unexpected conflict between these normally integrated components should be introduced occasionally as a means of obtaining objective evidence of their normal synesthetic integration.

On first consideration it may appear that our problem was very similar to that of others who in times past have attempted, rather unsuccessfully, to produce synesthetic effects through conditioning.

The major attempt to develop synesthesia through conditioning was apparently that of E. L. Kelly (1), who presented certain organ tones in combination with certain colored lights to a number of subjects. His test for conditioned synesthesia was an introspective report from his subjects that they either did or did not experience the corresponding color sensation when a given tone was sounded alone, or else that they heard the proper tone when the paired color-stimulus was presented by itself. Although these paired presentations were apparently continued for a long enough time to achieve positive results if they were at all possible, no success was obtained.

Comparison of the experimental means or methods of Kelly's experiment with those outlined above shows that while he did present certain combinations of visual and auditory stimuli, they were not used to achieve any end beyond themselves. Though his technique satisfied our first experimental requirement, it did not satisfy the second. Also his data were introspective reports from his *Ss*, while ours were errors in discrimination resulting from an experimentally-produced conflict between normally corroborative perceptual cues; his experimental criteria were subjective while those of this experiment are objective. Therefore, Kelly's set-up did not satisfy the third condition specified above. His *Ss* merely looked and listened because nothing else was necessary or demanded of them. It should be remembered that in the set-up of the present experiment the tones and colors involved constituted the necessary means for making difficult discriminations, and that success or failure in these discriminations meant success or failure in the work the *S* was paid to do. Our *Ss* did not try to achieve the results that meant success of the experiment; rather they tried to avoid them.

Method and Materials

The general method of the present experiment was to require the *Ss* to identify the color of a stimulus patch as either one or the other of two complementary colors, under circumstances in which the colors might vary from a maximum to a minimum saturation of either, that is they might be either strong or weak samples of two different hues. Identification of the colors was ordinarily facilitated by paired tones which were sounded before and while the colors were being shown, so that each color was normally indicated before it was seen by a distinct, characteristic tone. It is evident, therefore, that in spite of diminished or pale tints, discrimination between the colors would have been easy and certain if the tones were always dependable indicators. At irregular intervals, however, the indicator tone was a wrong or false one, influencing the *S* to make mistakes in his judgments when the discrimination was difficult, especially if the normal tone-color association was strong.

It is evident, therefore, that sight and sound stimuli ordinarily supplemented and reinforced each other in determining choices, but occasionally were in conflict, so that as the strength of the normal associations increased, interference and confusion increased for the reversed combinations. The effect was to motivate the *Ss* to pay ever closer attention to the stimuli, because making mistakes supposedly incurred a financial penalty. Consequently the *Ss* could not be passive toward the stimuli, but were obliged to use them as efficiently as possible in order to achieve a desired end. Since in the great majority of instances (95 percent of the practices)

the customary combination of color and tone occurred, that is, the indicator tone was correct, the effect of additional practice, in spite of errors, was to establish the normal associative connection ever more firmly, thus setting up a 'vicious circle' tending constantly to increase the susceptibility of the *Ss* for making errors as practice increased. For this reason, evidently, errors should constitute good evidence of sensory conditioning—which had developed in spite of the efforts of the *Ss* to avoid it.

The *Ss* of the experiment were eight university students who were paid for their services by the National Youth Administration. None of them had taken courses in psychology, and they were kept as ignorant as possible of the purposes and possible developments of the experiment. All of the *Ss* passed the Ishihara test for color vision, and all achieved better than the 40 percentile position on the Seashore test for pitch discrimination. They worked together in pairs, one student serving as *S* or observer while the other served as experimenter, giving directions, operating the apparatus, and keeping records. Every 20 min. they exchanged functions in order to avoid fatigue.

The experimental procedure was carried out in a dark room. The *S* was seated facing the screen of a color mixer, or chromatoscope, at a distance of six feet. The chromatoscope was especially designed and constructed for the purpose of this experiment. The screen was 13 cm. horizontally by 19 cm. vertically. It was translucent and was lighted from inside the mixer. The color could be readily and reliably varied from one extreme of saturation of a given hue to another hue, through an intermediate continuum of blends, all the while maintaining approximately the same brilliance. The intensity of illumination of the screen was approximately two foot-candles. When two complementary colors were used, as in this experiment, blending one color with another tended to reduce its saturation until, with an equal mixture of the two colors, a bright, neutral gray or white was produced. The colored light was supplied by two spotlight projectors mounted near opposite corners of one side of a light-tight box and supplied with appropriate filters to color the light. The spots were projected across the blackened interior of the box to a white screen on the opposite side, and thence the light was reflected back across the box to the translucent screen which was located between the spotlights. This reflection very effectively mixed and diffused the colored lights so that a very even blend was produced on the screen. The color stimulus could be varied from one extreme to the other by operating a slide to which shutters were attached, which reciprocally increased the light from the green spotlight while that from the red one was diminished, and vice versa. An indicating pointer was attached to the slide so that various blends could be identified on a scale. Thus it was possible to reproduce them at will, and also to measure and compare them.

Procedure and Explanation

The *S* was shown the screen of the chromatoscope, and then the lights were turned off and he was asked to close his eyes. He was then told that presently he would hear a musical tone, whereupon he was to open his eyes and note the color of the screen, report it as either *red* or *green*, and then close his eyes again.

The red color was actually carmine, and the green was a bluish green, so that the colors were approximately complementary, but for the sake of convenience they were referred to as *red* and *green* during the course of the experiment and the practice will be continued in this report. The tones were produced from organ pipes which were blown by the *E* for approximately a two-sec. interval. A lower tone, having a vibration rate of about 261, or middle C, characteristically accompanied the showing of red. The higher tone, usually accompanying green, was approximately the G above, or about 392 vibrations per second.

The chromatoscope was switched on just after the tone was sounded and both stimuli were continued for approximately two sec. and stopped at the same instant, which meant that the color stimulus was observed for slightly longer than one sec. Except for the lighted screen, the room was completely dark during experimentation.

A predetermined random order was followed in presentation of red or green stimuli. This fixed order, running through a series of 20 before repetition, was indicated to the *E* by a pattern of tacks driven in the edge of a writing board, and was read by sense of touch in much the same way that Braille letters are read by the blind. A number of these boards, indicating differens random orders, were used, so it was impossible to anticipate any particular order. As soon at the stimuli ceased the *S* reported the color, closed his eyes, and waited for the next trial. The

E immediately reported success or failure to the *S* by the words *right* or *wrong*, which record was simultaneously checked on a paper data sheet attached to the board on which the random order of trials was indicated. A rest interval of about five sec. elapsed after one trial was finished before the next began.

A new *S* was given five practice trials, which included the presentation of all combinations of colors and tones. Following these he was told: (1) that there would be a long series of such trials; (2) that the showing of red and green would be in irregular or random order; (3) that in some cases the color would be more intense than in others; (4) that while certain tones would usually precede certain colors, this would not always be the case and that he should be on his guard for exceptions in order to avoid making mistakes in his judgments; and (5) that his success in his work, and perhaps in keeping his job, depended upon making as few mistakes as possible.

After the introductory period the *S*s worked together in pairs, alternating in the capacity of *E* and *S* approximately every 20 min., usually over a two- to three-hour period.

As mentioned previously, showing the red color was commonly preceded by sounding of the lower tone, C, while green was preceded by the higher tone, G. Also these combinations of tone and color were reversed, that is the indicator tone was wrong, in five percent of the trials, or one time in 20, on the average. A chance order was arranged for these exceptions by whirling a miniature roulette wheel with 20 numbers on it and recording a number so obtained on each data sheet, which provided numbered spaces for the records. When this data sheet was attached to one of the writing boards, an extra thumb tack was placed opposite this practice number, as indicated by the tacks on the edge of the board. This arrangement indicated tactually to the *E* when the different or misleading indicator tone should be sounded. Thus it might come anywhere at random in a series of 20 practices, from the first to the twentieth, and, therefore, the *S* never knew when to expect a misleading tone.

The procedure as outlined, using all color stimuli of maximum saturation, was carried out for 5000 practices for each *S*. It occupied about 12 hours working time for the two students working together. During this period the *S*s did not have much difficulty in recognizing the color of the light stimulus when they looked at it. Because of the influence of the tone which characteristically preceded it, however, there was a growing temptation to prejudge it, and to get ready to give it the customary name. One might say that a habitual tendency was developed to make the same verbal response to the conditioned tone stimulus which was previously given to the color stimulus. Except for the reversals, in which the tone was a false indicator, it would of course have been feasible for the *S* to make his judgments with his eyes closed. The continuous possibility that the tone might be misleading, however, made it necessary for the *S* to pay critical attention to each color stimulus, which of course had the effect of establishing more and more firmly the associational connection between a given color stimulus and its usually-associated tone.

That this was the case was indicated by the fact that the *S*s would sometimes start to name the color indicated by the tone and then change their judgment, because, as they said, "it dawned" on them that the color was not the expected one. In such instances some *S*s reported that, on momentary first glance, the color actually seemed to be that indicated by the tone, but that in the process of visual perception, or 'dawning,' the hue seemed to change while they were looking at it, indicating not only that the mere verbal response was conditioned, but also that the visual manner of perceiving the color was also similarly conditioned. This tendency became so pronounced, especially during the later trials (after the first 5000), that four *S*s spontaneously developed a tendency to delay naming the color for a second or two after the stimuli had stopped because their color perception seemed to 'clear up and become more definite' by that time.

Fig. 1 presents graphically the relationship between errors and the number of practices, and also the number of *tests*, as reversals of the customary combinations of tones and colors were called. The number of errors shown by points on the graph is the number made during a period of 1000 practices or 50 tests. Practically all of the errors occurred on the tests and no others were counted. As will be noted, very few errors were made by any of the *S*s during the first 5000 practices and most of these were probably accidental, that is were slips of the tongue rather than false perceptions of color.

After a given *S* had completed 5000 practices, and had been given 250 test reversals of tones, he was continued as before, except that the saturation of the color, or admixture of hue, in the light stimuli was greatly reduced on every other practice, that is, in half of the practices. This meant of course that half of the reversed or test trials would also be made with these pale-color stimuli.

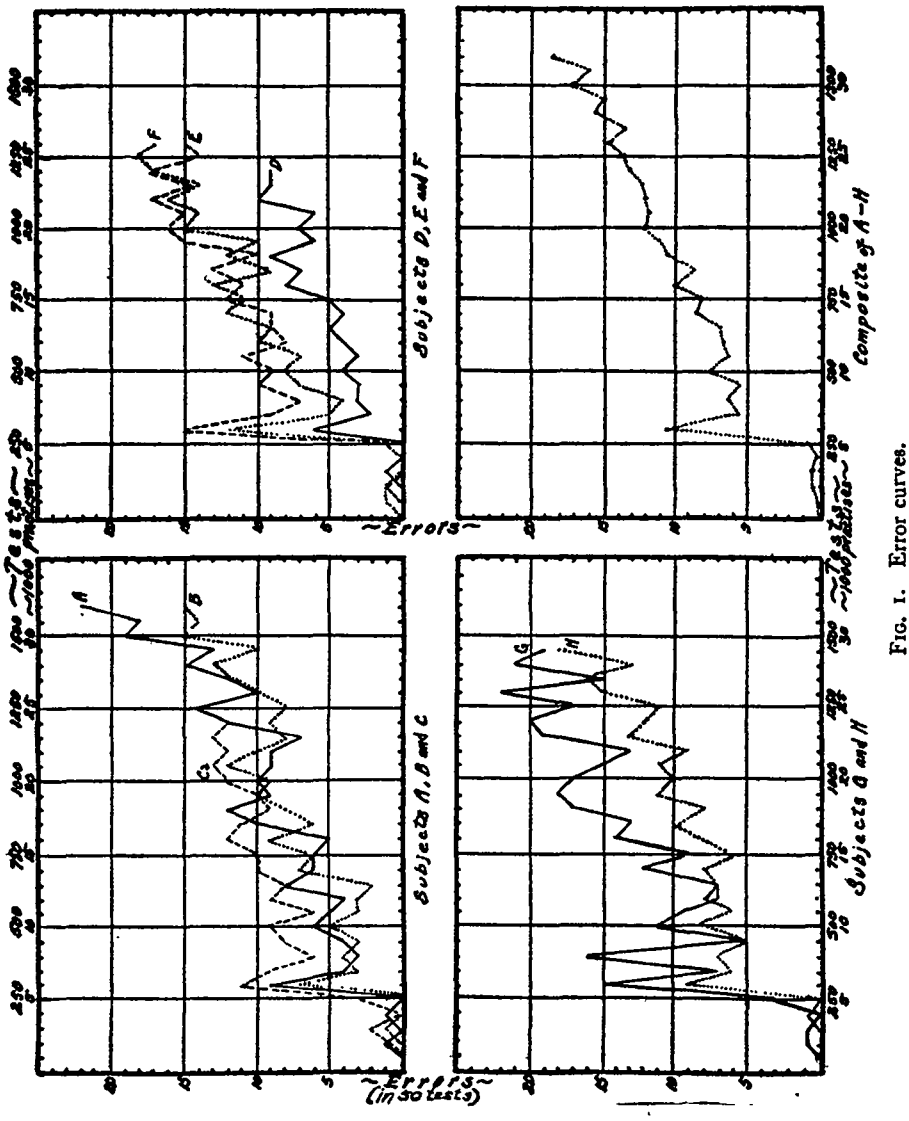

FIG. 1. ERROR CURVES.

For the first two *Ss*, numbers A and B, this reduction was achieved somewhat gradually and the degree of saturation was readjusted during a short preliminary period.[1] All of the other *Ss* were shifted to the standard pale-color stimuli on every other practice as soon as they had completed their preliminary training period with the saturated colors.

There was no expectation that a tone could ever be sufficiently conditioned as a color stimulus to counteract or reverse the perceptual effect of a color as highly saturated as the one by which it was originally conditioned. It was believed possible, however, that such a tonal stimulus might be sufficiently conditioned to reverse the perception of a pale, unsaturated color stimulus. The purpose in using only colors of reduced saturation on every other practice, and saturated colors on the other practices, following the preliminary period, was to avoid extinction of any conditioning already developed, and to reinforce it if possible. A certain amount of reinforcement was perhaps obtained from the paler colors but probably not a great deal. The reason for not using a larger proportion of practices involving saturated colors, and for not confining the tests to pale-color practices only, was that such limitation would have enabled the *Ss* mentally to exclude the possibility of making mistakes during the saturated-color practices, and also would have eliminated the motivation necessary to make conditioning effective during these trials.

Results and Interpretation

Fig. 1 shows the error curves for the eight *Ss* individually, and also a composite of these, as the practices continued beyond the preliminary period.

It will be noted, first of all, that immediately after the introduction of the less-saturated stimulus colors, all of the *Ss* showed a sudden increase in errors, and that for five of the eight *Ss* this increase was considerable. Secondly, it will be noted that after this initial debacle of errors, made chiefly on the first 50 tests after introduction of the paler colors, there was a tendency toward recovery during which period errors were reduced.

The reason for the sudden increase in errors is perhaps evident. After the *Ss* had become accustomed to the more intense colors, the paler colors seemed by contrast relatively indeterminate and lacking in color character of any kind. The *Ss* became disoriented in their color judgments and, of necessity, were compelled to rely very largely upon the indicator tones, which were of course misleading in the test trials. The *Ss* very naturally knew that test trials were interspersed with the others, and their suspicion undoubtedly persuaded them to disagree with the misleading indicator tones on some of the tests, which perhaps reduced recorded errors to some extent, but it also led them to disagree when the indicator tones were right, and therefore to make errors which do not show in the curves. For these

[1] The large number of errors made when the pale stimuli were first introduced led us to suspect that the task of discrimination had been made too difficult. A trial with new, unconditioned *Ss*, however, showed that it was not too difficult for them, so the saturation was permanently standardized at near the value we had originally selected. This was conveniently accomplished by attaching hinged stops which limited the range of movement of the slide on the chromatoscope whenever they were in place. We had no available means of measuring the admixture of hue in these low-saturation colors. It was very diluted or pale, but was readily recognized and named as *reddish* or *greenish* by five unconditioned persons who served as controls.

reasons, therefore, the curves probably do not represent the actual extent of failure to discriminate the colors.

The *Ss* generally reported a general lack of confidence in their judgments when the paler colors were introduced. In some of the tests, however, they reported more confidence than in others, and apparently their judgments on these tests were more often correct. For some reason, perhaps involving momentary distraction of attention, disorientation, or some other accidental factor, the indicator tones were much more disturbing for some tests than in others, and the perceptions of color were more uncertain in some practices than in others. On the whole, however, the number of errors in judgments seemed to constitute a good measure of actual perceptual interference.

The explanation of the second phase of the error curve, during which there was temporary recovery and errors diminished, is perhaps harder to find. Apparently the *Ss* became adjusted to some extent to the new situation and gradually revised their previous perceptual norms for color comparison, or perhaps developed new ones. Some of them reported that they "learned what to look for," which meant perhaps that they had learned to concentrate attention on significant cues.

The third, and perhaps the most interesting, aspect of the error curve is that after the sudden increase in errors, and subsequent decrease showing recovery of discrimination by the *Ss*, the curve begins to rise again with further practice and errors increase again over a considerable period. The only possible explanation of this continuous increase in errors seems to be that it is evidence of cumulative conditioning by which the substitute tonal stimulus was gradually strengthened by further association with the stronger or saturated color-stimuli, until it was able to dominate and reverse perception of the weaker color-stimulus in an increasing proportion of the tests. The habitual set, or expectancy of seeing a given hue after hearing the paired tone, became so strong that it overpowered the conflicting perceptual influence of the hue actually supplied, with the result that pale green was actually seen as pale red, or vice versa.

At least, this was the explanation offered by the *Ss*. It is possible that some of them had learned or surmised that such effects were to be expected in the course of the experiment, but it is not probable that they knew enough about it to anticipate developments. As mentioned previously, they were freshmen and had not taken courses in psychology. It should be understood also that they were not motivated to make such mistakes in perception, but rather to avoid them.

A possible fourth aspect of the composite curve, in so far as the part during which the unsaturated colors were shown (the latter or main part) is concerned, is that except for the initial decline it is

approximately a straight-line curve. The sudden rise in the curve during the first part of this period is probably best understood as an aftermath of the sudden shift from the saturated to the unsaturated colors. It would have been worth while, certainly, to have continued the practices for some time in order to develop the upper part of the curve, but limitations in available time of the *S*s made this impossible.

General observation of the behavior of the *S*s near the end of their period of service indicated to the writer that their errors probably would have continued to increase, perhaps at an increased rate, if they had continued with the practices. They seemed to develop nervousness as their errors increased, and showed a disinclination to go on with the experiment. Two out of the eight (A and G), at least, became uncertain and erratic in making their decisions and changed them so often that it was difficult to record them with certainty. One or two of the others seemed to become indifferent and apparently made decisions more or less at random without much attention to the colors. One of the *S*s (A) showed symptoms of incipient behavioral disorganization, failed to keep appointments, and tried to transfer to another job at a sacrifice of regularity and convenience in hours. Although most of the *S*s said that they preferred to act as observers during the first part of the experiment, they all preferred the job of serving as experimenter during the latter part of it. They reported that sitting as an observer was more tiresome, and also that it made them 'jumpy.'

Actually the impression of the writer was that unwittingly the experiment had achieved about as much success in developing neurosis as in creating synesthesia. As a matter of fact, it is quite evident that the procedure necessarily developed a conflict between opposed perceptual tendencies and resultant choices which greatly resembles the conflict situation of Pavlov's dogs (**5**), obliged to discriminate increasingly similar geometric patterns; of Maier's neurotic rats (**4**); and of other victims of experimental or accidental neurosis. As the strength of the usual combinations of tone and color were strengthened, the reversed combinations were increasingly in conflict. This was, of course, the planned set-up, which was intentionally responsible for the increase in errors with additional practice.

Testing Validity of Evidence

There is perhaps some justification for considering whether or not the conditioned response to the tonal stimulus was not primarily a verbal response rather than a perceptual response; that is, that the *S*s were directly conditioned to say the word *red*, for instance, rather than that the word was a report of what they actually saw. There is

no reason to doubt that conditioning did facilitate saying the words most frequently associated with the tones. The *Ss* did show a tendency at times toward speaking the associated word thoughtlessly or mechanically as soon as the tone was sounded. It is very probable that this tendency was responsible for some of the errors, especially in the early part of the experiment. The automatic corrective for such impulsive responses, however, was the fact that they resulted in making mistakes which the *Ss* wanted very much to avoid. They soon learned to be on their guard against making such rash judgments, and, as previously mentioned, four of them spontaneously developed the practice of waiting for a brief time after both stimuli had ceased before making their judgments, partly at least because they believed that the color image cleared up and became more dependable by that time. The manner of the *Ss* in making their verbal reports also tended to give the impression that in most instances they were reports of actual visual observations rather than mere mechanical vocalizations.

Still, it cannot be denied that the conditioned verbal response was actually a part of the total organismic response, and undoubtedly contributed its share in determining decisions about color. One of the *Ss* reported that, even after deliberate delay of his report, the word indicated by the tone still "trembled on the tip of my tongue." Perhaps the best interpretation is that the verbal response was as much a means by which the perception was mediated as was the word a resultant of the perception.

In the hope of testing the hypothesis that the supposed synesthetic effect was merely a conditioned verbal response to a tonal stimulus, that the supposed distortions of color perception were perhaps merely slips of the tongue, an additional test was devised and given to two of the *Ss* (G and H) when they had nearly finished their part in the experiment.

They were trained to use an extension rod to operate the slide on the chromatoscope so as to adjust it for what appeared to them to be a point neutral between the two colors, or the best possible white, moving in on one trial from bright red toward the green, and on the next from bright green toward the red, in alternating order. After each adjustment was made, a reading of the scale of the chromatoscope was taken. When the *Ss* had attained some degree of efficiency, the exercise was continued as before, but now one or the other of the tones to which they had previously been conditioned was sounded quite continuously all the while they were adjusting the chromatoscope for white. A scale reading for such adjustment was made and recorded, and then another adjustment was made starting with the other color, and perhaps with the other tone sounding.

Adjustments were made alternately, starting with different colors, but the high and low tones were sounded in random order. One hundred readings were made for each of the two *Ss* .

Frequency distributions of readings of the scale of the chromatoscope were made, one while the lower tone, C, was sounded, and one while the higher tone, G, was sounded. The mean scale value for 100 combined readings with the lower (red) tone was 4.64, and was displaced from the point of adjustment for white (5.00) toward the green, indicating apparently that additional green was needed to compensate for the coloring effect of the lower (red) tone. The mean scale value for 100 readings with the higher (green) tone sounding was 5.42. The difference between the means was .78, and the standard error of the difference in the means was .19, affording a critical ratio of 4.1. This seems to constitute reasonable proof that the tones actually exerted a coloring influence upon the visual perceptions, independently of any verbal response.

Another possible explanation of the increase in errors as the *Ss* continued with the experiment is that they made more errors because they had lost interest in their work and did not make the effort to avoid errors that they did earlier. Perhaps the threat of losing their job became less effective, since they were nearing the end of their employment period. In other words, it might be suspected that errors in discrimination of the colors would have increased regardless of whether or not the tones accompanied the showing of them.

While it must be admitted that the work was routine and long drawn out, and perhaps monotonous, there is no reason to conclude that it was more tedious than the usual drudgery of NYA students. As mentioned, the *Ss* alternated in the roles of *E* and *S* every 20 min., which afforded considerable relief from monotony. Also it was natural that the two *Ss* working together should compare their scores quite frequently, and this seemed to inject an element of competition between them which added interest to their work. On the other hand, it was unavoidable that they should recognize that their errors were increasing rather than diminishing and this may have contributed to a sense of failure, defeatism, and also to the nervousness previously mentioned. Nervousness, however, was evidently more of a result than a cause of increase in errors. It is possible that the threat of discharge lost effectiveness with time. Still it was known that other NYA students had lost their employment because faculty supervisors had reported them as unreliable or inefficient. The NYA employees generally showed a sense of obligation and responsibility and were hopeful of future employment if they were successful with their present work.

In order to test the hypothesis that errors had increased because of loss of motivation, and irrespective of the influence of the tones, the following procedure was carried out with four *Ss* (E, F, G, and H).

At or near the end of their practices with the tones, they were asked to go through exactly the same routine, except that the *E* substituted the word *now* for the tone as a signal for the *S* to open his eyes and make a judgment of the color stimulus. It will be noted that the same word was used for both colors and therefore could provide no preliminary clue as to what the color would be. The same random method of selecting the test trials on which the customary tones would have been reversed, if they had been used, was carried out. Only errors of discrimination on these trials were counted. Each *S* completed 1000 practices, including 50 test trials, in this situation. Subject E made 5 errors, F made 3 errors, G made 6 errors, and H made 3 errors. The number of errors without the tones was less than one-fourth the number they had made just previously, during an equal number of trials with the tones, which would seem to demonstrate that the tones actually did contribute toward the increase in errors.

Two of the *Ss*, G and H, immediately after completing the test just described, were individually given 100 trials with the arrangement that every other trial presented one or the other of the colors of maximum saturation at random. It was preceded and accompanied by the usual tones, as was the customary practice in order to reinforce conditioning during the period of increasing errors. On the other or alternate trials, however, in which pale or unsaturated colors had previously been used, a neutral or best-white stimulus was used instead. This neutral color was preceded and accompanied, as were the unsaturated stimuli, by the high and low tones in random order. These tests were administered by the writer, so that neither of the *Ss* anticipated the nature of the stimuli or purpose of the tests. In every instance the reported color of the white stimulus was that indicated by the tone. One of the *Ss* afterwards informed the writer that he suspected during the course of the tests that the pale stimuli were actually white, but that nevertheless they really appeared colored to him. The other *S* said that it did not occur to him that the stimuli were white.

The latter *S* (G) made an interesting comment that in one of the trials described above the tone was accidentally discontinued before the chromatoscope lights were turned off, and that on cessation of the tone the light stimulus changed from red (the color induced by the tone) to green, rather than to its actual white. He was tried out again in this situation and apparently verified his observation. If the effect is genuine, it would seem to mean that the laws of color

contrast, perhaps as relating to after-images, do not depend always upon specific physical stimuli and may be psychological as well as physiological. The same *S* also volunteered that he saw a clear image of the screen of the chromatoscope, and of the color normally associated with a given tone, when this tone was sounded while his eyes were closed or in the darkened room. He could get an after-image of the lighted rectangle which was of a color complementary to the actual color, but his after-images, when the rectangle was psychologically colored from the effect of a tone, were dark only with no color noticeable.

Summary and Conclusions

A low tone was sounded before and during the showing of a reddish light, and a higher tone was similarly associated with a bluish-green light, for 5000 presentations to eight *S*s, who reported the color of the seen stimulus on each presentation. They were motivated to pay close attention to the color, and not to depend upon the accompanying tone, by occasional reversals of the usual tone-color combinations. These reversals influenced them to make mistakes in their reports, for which, supposedly, they might lose their jobs. Thus, the attitude of the *S*s toward the stimuli was active or purposive, rather than passive. After completing these practices, unsaturated color stimuli, pale but recognizable, were substituted on alternate practices, and for one half of the reversed or test combinations. When the tones were thus switched, many mistakes were made in identifying the hues of these pale colors. The same combinations of stimuli were continued with these *S*s for about 20,000 additional presentations, involving 1000 interspersed test reversals of tone. Although there was a temporary recovery from earlier errors, the proportion of errors continued to increase with additional practice.

The errors may be interpreted as an effect of synesthesia which was developed through conditioning. This interpretation is borne out by evidence that the errors were not due to diminished interest or effort, and that they involved an actual distortion of visual perceptions rather than errors in verbal responses only, or mere slips of the tongue.

Whether or not the developments of this experiment are representative of true synesthesia, or merely what one writer has called pseudo-synesthesia, must be left to the personal judgment of the reader. It has sometimes been argued that real synesthesia is always inherited. If this definition is accepted, then of course the conditioned linkages of stimuli and responses, presently reported, are not synesthesia. Also, if it is presumed that perception is purely an affective phenomenon, to be observed only by introspection, and not

dependent upon motor responses of any kind, then the present evidence is not pertinent with respect to the problem of synestheisa.

Many of the traditional cases of synesthesia have exhibited very extreme and novel complications. Some of the sensory combinations reported in modern scientific literature have also been quite sensational. They are reviewed by Langfeld (2, 3). The color, tone, number, and letter associations of the blind, particularly, are sometimes very complex and intricate in structure. The obsessional character of some, and marked elaboration of many, of these combinations suggest that they may have a compensatory or symbolical significance for the *Ss* similar to that of the graphic and vocal elaborations characteristic of various regressional disorders.

It is very probable that certain types of unadaptive personality might become disorganized sooner and make more errors than others in this present experimental situation. The behavior of some of our *Ss* suggested this possibility. Rigid inflexibility of associations in the earlier practices would evidently contribute toward such later disorganization. Innate differences also probably culminate in later differences in the dynamic balance of a personality. It is possible that the present technique might be adapted to produce experimental neurosis, or perhaps to diagnose or predict incipient neurotic tendencies. Some of our *Ss* showed more neurotic symptoms than others in the experimental conflict situation.

The general or theoretical implications of this experiment might be listed as follows:

1. That tonal stimuli can be conditioned to influence judgments of color stimuli in a manner which is apparently synesthetic.

2. That the mode of purposive use of sensory stimuli influences the possibility of conditioning their perceptual and adjustive responses, since the present experiment, unique in providing interdependency between sensory data in guiding organic adjustments, was successful in influencing judgments of color by means of sound stimuli, whereas previously-reported experimental attempts were not successful.

3. That sensory or perceptual data are not inherently distinguishable from each other, or from the supposedly-independent motor adjustments which they mediate, but that such distinction is necessarily a function of an effort to resolve a conflict in a larger program of organic and biological integration. The reason sensory data have had such unquestioned, common-sense acceptance, as unconditionally and absolutely ultimate, is that in normal everyday living only certain typical variations in environmental factors occur, and that adjustment to these is effectively achieved by our normal assortment

of sensory modalities. Abnormal conditions, however, may impose striking transformations of these modalities, as the present experiment demonstrates.

The practical implication of this experiment is the evident necessity for integrating sensory data with motor functions and the possibility of supplementing the data of a given defective sense by data from another sense. The various senses obviously have much more in common than is generally realized. Such supplementation is strictly limited, however, by the possibility of differentiating and integrating the data of the substituted sense into the general adjustive pattern normally supplied by the defective sense. Defective vision, for instance, may be, and often is, supplemented, to a much greater extent than even the visually handicapped are aware, by well-organized auditory data. The therapeutic problem is to facilitate this differentiation, organization, and substitution, partly through training, and perhaps mechanically, in part. Thus it may come to pass that the blind shall see again—through their ears.

(Manuscript received December 6, 1943)

REFERENCES

1. KELLY, E. LOWELL. An experimental attempt to produce artificial chromasthesia by the technique of the conditioned response. *J. exp. Psychol.*, 1934, 17, 315–341.
2. LANGFELD, H. S. Synesthesia. *Psychol. Bull.*, 1926, 23, 599–602.
3. LANGFELD, H. S. Synesthesia. *Psychol. Bull.*, 1929, 26, 582–585.
4. MAIER, NORMAN R. F. *Studies of abnormal behavior in the rat.* New York: Harpers, 1939.
5. PAVLOV, I. P. *Conditioned reflexes.* London: Oxford Press, 1927.
6. STRATTON, G. M. Vision without inversion of the retinal image. *Psychol. Rev.*, 1897, 4, 341–360.