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AN EXPERIMENTAL ATTEMPT TO PRODUCE ARTIFICIAL CHROMÆSTHESIA BY THE TECHNIQUE OF THE CONDITIONED RESPONSE [1]

BY E. LOWELL KELLY

Connecticut State College

I. Introduction

It is a well known although curious fact that some persons possess a tendency for perceiving certain types of stimuli, simultaneously, in more than one sense field. For some individuals, tones are not only heard but seen either as colors or as forms. Other persons find that letters and numbers, whether printed or spoken, have specific colors. Such a tendency toward double sensations is known as synæsthesia. While there is thus, theoretically, a large number of possible combinations of the various sense fields, it so happens that vision and audition are the sense modalities most frequently involved. The particular type of synæsthesia in which colors accompany auditory stimuli has been variously referred to as: *Farbenhören*, *audition colorée*, *Akustish-chromæsthesia Synopsie*, colored hearing, pseudo-chromæsthesia, and chromæsthesia. The current practice in the English literature, however, seems to favor the last mentioned term. Throughout this report,

[1] This experiment was conducted at Stanford University under the direction of Prof. Walter R. Miles.

the word 'chromæsthesia' will be understood to denote that tendency of auditory stimuli to arouse simultaneous sensations or images of color as well as of sound.

Although the literature bearing directly or indirectly on the subject of chromæsthesia is very extensive it consists largely of such contributions as: introspective reports, hearsay evidence, portrayals of individual cases, and similar anecdotal and descriptive articles. Inasmuch as several excellent summaries have been made of this literature, Krohn (12), Mahling (16), Argelander (2), and Wheeler (27), and since it has no direct bearing on experimental investigation in the field, it will be given but brief review.

One of the first accounts of this interesting phenomenon is to be found in Goethe's (9) *Theory of Colors*, written in 1810. Goethe refers to a case reported by Hoffman (10) as early as 1786. Hoffman describes the case of a Swiss magistrate and painter who was talented with the ability to see colors as accompaniments of sounds. For this individual, tones of musical instruments called forth unusually strong color sensations, the high notes resulting in especially vivid color impressions.

According to Krohn (12), the first case of chromæsthesia to be reported in the medical literature is the detailed description given by George Saches in his inaugural dissertation at Erlangen in 1812. The person he describes was an albino who associated color, not only with musical tones, but also with letters of the alphabet, figures, names of cities, days of the week, dates, epochs of history, and even with phases of human life. Of especial interest is the fact that, when a musical tone was associated with a color, the letter indicating that note was associated with the same color.

In 1843, Gautier (8) published additional descriptions of persons with tendencies toward chromæsthesia. Of greater significance was his report of being able to produce artificially these false color sensations by the use of the drug, hasheesh. This is particularly interesting since Havelock Ellis (5) records a similar tendency to artificial synæsthesia as one of the effects of the drug, mescal or peyote.

Probably the most interesting case study of chromæsthesia reported is that of Nussbaumer. When a student at Vienna, at the age of 23, he published (18) a description of both his own and his brother's chromæsthetic tendencies. A summary of this interesting self-description has been made by Lewes (13). Galton (7) in his studies of mental imagery discovered and reported many interesting cases of synæsthesia particularly number forms and colored vowels. His work attracted wide attention to the subject and stimulated a large number of contributions to the literature. Case after case could be cited, but these would add little, if anything, to the solution of the problem proposed for investigation. Anyone interested in reading descriptions of such cases can readily locate them by reference to the extensive bibliographies available. That of Mahling (16) contains 550 titles and Argelander (2) gives 466 titles.

We shall now review briefly the various theories that have been advanced as an explanation of this 'curious' phenomenon. Before reviewing the theories, however, let us consider the following facts regarding chromæsthesia which the theories seek to explain.

In the majority of cases, chromæsthesia seems to be related to a high degree of imagination. Rarely is there a defect of either vision or hearing, and in a number of cases, these senses have been especially keen. For instance, Nussbaumer was able to distinguish eleven partial tones without the use of resonators and without practice. With most persons the color-sound associations date back to very early years; many individuals are unable to remember when they did not have such tendencies. Sound, especially speech and musical tones, are most frequently linked with color, but in some cases, letters and whole words are colored. The two sensations are usually inextricably linked and appear simultaneously. There is no measurable difference in the reaction time for responding to the linked sensations.

The tendency toward chromæsthesia in some cases seems to be hereditary. In almost all of the cases reported, other individuals of the same family have had similar tendencies.

Lundborg (14) has recently investigated colored hearing in three generations of a Swedish family and concluded that it is probably a dominant Mendelian factor but not sex linked. In spite of the evidence in favor of an hereditary concept of chromæsthesia, such a theory must be broad enough to explain wide idiosyncracies, since, as Galton (7) states, "No two people agree, or hardly ever so, as to the color they associate with the same sound." Certainly these facts indicate the influence of experiential factors which must be considered in any adequate theory.

Other facts to be explained are these: fatigue seems to facilitate the color impressions; certain drugs may artificially produce these phenomenon; there is a remarkable constancy of specific color-sound associations over long periods of time; the intensity and clearness of the colors may be different for the right and left eye; and practically all cases agree that it is the sound itself, and not the meaning, which calls up the sensation or image of colors.

Although many possible explanations of synæsthesia have been advanced by various writers, they seem to fall into two main groups: physiological and psychological. In general, it may be said that the physiological theories also assume an hereditary view of synæsthesia, while the psychological ones seek to explain the facts on an environmental or experiential basis, but this is not always the case. Certain physiological theories also belong to the environmental group. The reverse, however, does not hold. All psychological theories are stated in terms of past experience.

It must be admitted that none of the proposed theories, either physiological or psychological, satisfactorily explains all of the facts mentioned above. In the first place, any theory of chromæsthesia necessitates the acceptance of one of the various theories of color vision, none of which have received universal acceptance. Assuming, however, that a satisfactory explanation of color vision were available, there is still need for a suitable explanation of why two or more types of sensations are aroused by stimuli which are ordinarily perceived in only one sense field. Let us consider first the physiological theories that have been advanced.

The earlier writers considered cases of chromæsthesia as pathological in nature. Carnaz in 1848 (3) explained them as due to a hyper-æsthesia of the sense of color, probably due to some optical lesion. Lussana (15), in 1873, suggested that the brain centers for perceiving color and sound might be contiguous, and thus have reciprocal influence on each other. Nuel (17), agreeing with this view, suggested that these secondary sensations might be due to nervous irradiation of sensorial currents. Pouchet and Tourneux (20), with others, have held that chromæsthesia results from abnormal crossing or even anastimosis of afferent nerve fibers. Fêrè (6) considered the phenomenon to be due to a particular tonus of the nervous system, produced either by drugs or an unusual experience. The action of hasheesh and mescal, already referred to, offer a certain amount of evidence in favor of this theory.

A novel physiological theory of chromæsthesia as well as of synæsthesia in general was suggested by Titchener (23), who explained the tendency toward double sensations as resulting from an unusual elasticity of the walls of the cerebral arteries. A rush of blood to the auditory center might also affect the visual center, thus resulting in colored hearing. While this theory is interesting and fits in nicely with certain known facts concerning chromæsthesia, such as the loss or reduction of the tendency with increasing age and its occurrence in moments of emotional stress, it nevertheless does not offer a very satisfactory explanation of the phenomenon. Perhaps, its most obvious limitation is that the relatively slow change in blood pressure would not account for the practically simultaneous appearance of the double sensations.

While considering the nature of synæsthesia in general and chromæsthesia especially, it occurred to the present writer that these phenomena might be nothing more than examples of the well known conditioned reflex. In surveying the literature, it was discovered that Wheeler (27), after an extensive investigation of the synæsthesias of a blind subject, had ventured to define synæsthesia as 'an immediate and permanent conditioned reflex.' He admitted that such a definition was purely hypothetical and offered it merely as being as good or better than any previously proposed theory. He failed, however, to suggest ways and means of producing an 'immediate and permanent' conditioned reflex, or to specify why such might occur in synæsthetic subjects.

Many investigators have felt that a physiological explanation of synæsthesia is impossible and that a psychological one is needed. While most of the theories advanced by this group are based on the law of association of ideas, they differ in certain respects, and will be reviewed briefly.

Kaiser (11) suggested as an explanation of a case of 'colored seeing' that the subject himself puts the color into an intimate association with the words in order to engrave them better upon his memory, the association extending back to early childhood, and while it is at first voluntary, it later becomes spontaneous. Stevens (22), Schenkl (21), and others have offered similar explanations, holding that the subject either intentionally or accidentally associates the two types of sensations and thereafter, the one arouses the other. Such theories are not by any means extinct. In his recent text, Woodworth (28) offers only the following brief explanation of the phenomenon: "The synæsthesia probably resulted in childhood from playfully linking the sensations together." Evidently some persons have highly developed powers of introspection—even in childhood!

To the present writer, the psychological theories which have been proposed seem superficial and inadequate. According to Titchener (23), "Attempts have been made by trained and interested observers to trace back their synæsthetic experiences to associations formed in childhood; but in spite of all their efforts, they have ended in failure." The suggestion that the phenomenon is an example of the conditioned reflex represents an attempt to offer a combined physiological and psychological theory, that is, to explain the known facts of psychological association on a neurological basis. The fact that the order of synæsthesias are never reversed forcibly suggests the analogous unidirectional action of the conditioned reflex.

As mentioned above, almost all of the extensive literature bearing on the subject of chromæsthesia is either descriptive or anecdotal. There has been much writing and theorizing concerning the subject, but very few experimental studies have been carried out to clear up the points in question. The small amount of experimental work that has been done may be divided into three general groups: (1) repeated observations (with the aid of controlled auditory stimuli) on individual cases of chromæsthesia; (2) group experiments with unselected populations using controlled auditory stimuli with the object of establishing qualitative laws between sensations of tone and color; and (3) so-called statistical studies or surveys which have sought to determine the prevalency of chromæsthetic tendencies. It should be pointed out, however, that with the exception of the first type of study mentioned, the investigators were studying associations of sensations and not the spontaneous double sensations which are found in marked cases of chromæsthesia. Surprising as it may seem, apparently none of the many investigators who have been interested enough in chromæsthesia to contribute to the literature of the subject, have made any attempt to establish this tendency toward colored hearing in normally non-synæsthetic subjects. Off-hand, it would seem that at least some of the many theorists would have subjected their theories to such a crucial experimental test. This being the case, the writer felt that it would be desirable to conduct an experimental attempt to establish artificial chromæsthesia under controlled conditions.

II. Technique of the Experiment

Inasmuch as many students of chromæsthesia have held that the sensations are the result of associated past sensory experiences, and since the conditioned reflex theory presupposes a similar association of stimuli, except that they must be experienced under certain rigid conditions, it was decided to make the experimental situation such that it would determine the possibility of chromæsthesia resulting either from simple association or from conditioning, thus testing both of the theories at the same time. At this point, the writer wishes to emphasize the fact that he had no personal interest in either theory. He merely wanted to put the hypothesis to an experimental test. The success of previous investigators in establishing conditioned reflexes in human subjects led him to believe that it might be possible to condition an artificial chromæsthesia.

As is well known, the necessary conditions for the formation of a conditioned reflex are two (19): (1) there must be an existent reflex, which may be either a conditioned or an unconditioned one; and (2) the conditioned and unconditioned stimuli must occur either simultaneously or the conditioned must precede the unconditioned one. It would seem that these requirements could be met easily, since (1) there is an existent reflex or response, that of color stimuli eliciting the sensation of color; and (2) it is a fairly simple matter to arrange for the simultaneous presentation of the conditioned and unconditioned stimuli (tone and color pairs). The possibility of meeting the latter is certain since it obviously entails nothing more than overcoming technical difficulties in the devising and building of the necessary apparatus. Satisfying the first, however, that of utilizing an existent reflex or response is a somewhat more questionable possibility.

Does the act of perceiving a color involve either a reflex or a response? We are face to face with the unanswered question of the nature of sensation and with the problem of where sensations are perceived. To say with the structuralists that sensations occur in consciousness does not suggest any possible clue as to where they take place or as to what physiological or neurological activity is involved. Physiology and neurology have likewise failed to answer the question in an adequate manner. To be sure, we know that certain end organs, nerves, and brain areas are necessary for the conscious perception of sensation, but the exact mechanism involved is as yet undetermined. It does appear, however, that some type of a response takes place, and upon this assumption, the validity of the present experiment must rest. Recently Allen (1) has maintained that afferent sensory impulses not only arouse characteristic sensations in the cortical centers, but furthermore arouse certain efferent currents or reflexes which either heighten or depress the sensitivity of their receptors. In view of the unknown nature of the assumed response, however, the present problem is hereafter referred to as an attempt to establish a *conditioned response* rather than a *conditioned reflex*.

This brings us to one of the most interesting theoretical aspects of the investigation. If it is shown that it is possible to establish a conditioned response upon the act of perceiving a sensation as the unconditioned response, a valuable contribution will have been made to our understanding of the true nature of sensation. On the other hand, if under the proper conditions, such conditioning fails to occur, this will constitute one line of evidence that sensations are neither reflexes or responses, or at least not the ordinary type of reflex or response which has been shown amenable to conditioning.

As a part of the experiment, it seemed advisable to make use of a number of different stimuli, both conditioned and unconditioned. For this purpose, it was decided to use the eight notes constituting the C major diatonic scale each paired with a different color. Essentially then, the experiment represented an attempt to establish a number of conditioned responses at the same time. In order to make sure that this complication could not be the cause for a possible failure of the experiment, it was also decided to devote a part of the experiment to single tone-color pairs and thus determine the possibility of establishing a simple crossing over of the two sensations.

In still another respect, this experiment differs from other conditioning experiments, in that neither the conditioned nor the unconditioned stimuli used appeal to any strong physiological drive such as sex or hunger. It is conceivable that it might fail because of this fact were it not that Cason's (4) experiments with the pupillary and eyelid reflexes were successful in spite of a seeming lack of motivation.

In order to take advantage of any possible existent relationship between color and tone (generally known as the

Newtonian parallel) it was decided to pair each note of the octave with the color occupying the same relative position in the spectral series as the note occupies in the musical scale. Practical exigencies made it desirable to use only six different colors in addition to white and these were paired with the notes in the following manner:

Note	Color
C	White
D	Red
E	Orange
F	Yellow
G	Green
A	Blue
B	Violet
C[1]	White

Theoretically, for fulfilling the conditions necessary for the building up of a conditioned reflex, any color might have been paired with any tone. However, since it was possible to meet the required conditions and also retain the order suggested by the Newtonian parallel, it was considered wise to do so.

The pairing of white with both the upper and lower 'C' calls for a word of explanation. No one has reported any relationship between the colors accompanying octave pairs in actual cases of chromæsthesia. Since the frequencies of such pairs are always in the ratio 1 : 2, it seemed logical that if conditioning did occur, and if any color at all was seen upon the presentation of a tone one octave higher, it should be the same color as elicited by the same note an octave lower. In case the hypothesis did not prove correct, this procedure could not invalidate the entire experiment since six other different color-tone pairs were used.

Another interesting theoretical aspect of the experiment was the possibility of its revealing new facts regarding color vision. Let us assume for the moment that conditioned responses were established for each of the above tone-color pairs. According to the pairing, the subject would see yellow upon hearing the tone 'F' and blue upon hearing the tone 'A.' What color would be seen if both 'F' and 'A' were sounded simultaneously? Would it be green, grey, or a motley mixture of the two, or even something else? The answer to this and similar questions which might be asked would be exceedingly useful to students of visual and optical phenomena.

Apparatus

The essential demands of an adequate experimental set-up for this problem were as follows:

1. It must include apparatus capable of producing sustained tones corresponding to the eight notes of the C-major diatonic scale.

2. It must provide for presenting any one of seven colors of light *all in the same place*, in order to prevent any spatial orientation of the colors.

3. It must be so designed and constructed that certain tone color pairs will always be presented simultaneously.

4. It must be automatic and operate at a constant speed in order to assure consistency of the stimulus series.

5. It must be practically devoid of extraneous noises.

These requirements were all fulfilled in the set-up which was constructed for the experiment. Specifically, they were met as follows:

1. After much casting about for a suitable means of presenting the sustained tonal stimuli, it was at last decided to use a 'grind organ' such as was popular in this country several years ago. A thorough search failed to discover a suitable instrument of this type and other possibilities were considered. At length, the writer decided to construct a 'grind organ' by making use of a piano keyboard accordion, an electric blower unit,[2] and a roller device for making it 'self-playing.'

2. At first it was planned to use eight colored electric light bulbs, arranged in a row, as the unconditioned stimuli. It was evident, however, that such an arrangement would result in a spatial orientation of the colors. Since this would have added an unwanted factor to the unconditioned stimuli, a possible means of presenting all of the colors in the same place was sought. This was accomplished by the use of seven projection lanterns, each bearing a colored gelatin filter and all focused on the same area of a white screen. In order that each square of color would appear to be exactly the same size and shape and in exactly the same location as all others, a white square was laid off on the screen and bounded by dull black cardboard.

3. The simultaneous presentation of the tone-color pairs was accomplished by means of electrical contacts soldered to each of the eight keys of the accordion. Each time one of these keys was depressed to produce a tone, the contacts closed; this in turn operated a relay which lighted the projection lantern carrying the color of filter with which the tone was paired.

4. The apparatus was made to function automatically by means of a revolving cylinder carrying studs which depressed each of the keys in a prearranged order. Constant speed of operation was assured by the use of an electric phonograph motor geared to the roller.

5. Preliminary experimentation showed that the only noisy parts of the set-up were the blower unit and the relays. In order to eliminate these distracting noises, the blower was placed in a room on the floor above and the compressed air led to the ac-

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[2] A used vacuum cleaner motor, fan, and housing served admirably for this purpose.

cordion by means of a one-inch pipe, and the relays were placed in a room adjoining that which contained the tone unit and the projectors.

With the exception of the blower unit and the relays, the entire set-up was arranged in a room 11 feet wide and 15 feet long. The screen was placed directly in front of the tone unit, hence the tones seemed to emanate from the colors projected on the screen, the illusion being similar to that of the talking movies. The seven projection lanterns were mounted on a table which was elevated to a sufficient height to throw the colors over the heads of the subjects who were seated in the room.

In order to record the number of repetitions of the paired stimuli, a small Veeder counter was connected to the playing cylinder. The same movement of the rod which actuated the counter was used to operate an automatic stopping device which could be set to shut off the power supply and thus stop all of the apparatus at the end of from 1 to 30 revolutions of the playing cylinder. This device permitted the experimenter to serve also as a subject, since it relieved him of the necessity of counting the number of stimuli presented and of stopping the apparatus at the proper time.

In order to make possible the continued repetition of a single tone-color pair, a 'magnetic finger' was constructed, which could be used for depressing any desired key. This finger was controlled by means of a five segment commutator mounted on the shaft of a synchronous electric motor. A second automatic switch was used to stop this motor at the end of ten minutes or after 50 repetitions of the stimulus pair. For the individual tone-color pairs produced by the magnetic finger, the duration of each stimulus was approximately 9 seconds with a three second interval between successive stimuli.

The rate and also the duration of the presentation of the entire scale of tone-color pairs was determined by the speed of the electric motor driving the playing cylinder. For the purpose of the experiment, it was adjusted so that this cylinder made one complete revolution in 45 seconds. Since 16 pairs of stimuli (one ascending and one descending scale) were produced by each revolution and since there was an interval of approximately 2 seconds between each scale and one-half second between each stimulus pair, the actual duration of each tone-color pair was approximately 2 seconds.

It has been determined that conditioned responses are established when the conditioned and the unconditioned stimulus occur simultaneously, or the conditioned stimulus precedes the unconditioned, but not vice-versa, hence the apparatus was adjusted so that the tones appeared either simultaneously with or else just before the colors. Since the keys of the organ had to open slightly before the electrical contact was closed, the tones were produced as soon as, or slightly before the colors were thrown on the screen.

The apparatus, from the mechanical and electrical point of view, functioned perfectly throughout the course of the experiment. It is felt that it not only provided adequate stimuli, but also met all other requirements for carrying out the experiment in a satisfactory manner. Psychologically considered, the tonal stimuli were of course not pure tones, since each note of an accordion is produced by two vibrating reeds each accompanied by its characteristic overtones. However, the presence of these secondary cues only served to make tones more easily distinguishable and therefore all the more desirable. Likewise the color filters were not chosen with regard to their pureness of color but rather for their readily distinguishable nature.

III. Experimental Procedure

The experiment itself was in part a group experiment and in part an individual experiment. The group experiment constituted an attempt to establish chromaesthesia for an entire octave of the musical scale; the individual part consisted in the attempt to condition one tone to one color only.

In the group experiment, the subjects were seated in front of the screen and all lights extinguished. In order to assure a similar mental set on the part of all subjects, the purpose and technique of the experiment were explained before the experiment began. The only instructions given to the subjects were: "Look at the colors and listen to the tones," but it was specifically stated that the subjects might assume any attitude desired, or use any method they wished in reacting to the stimuli. In the group experiment, the stimuli were presented in series of 40 complete scales, 20 ascending and 20 descending ones. Two such series or 80 repetitions of each of the 8 tone-color pairs were presented at each sitting. The group met four times per week: Monday, Tuesday, Wednesday and Thursday at 5 P.M., so that a total of 320 repetitions were presented weekly for 7 weeks.

For the individual experiment, the subjects were each assigned a single tone-color pair. These subjects were instructed in the operation of the apparatus, and at times convenient to themselves, entered the dark room individually for their part of the experiment. They, too, sat directly in front of the screen, and followed the same instructions as the subjects in the group experiment: "Look at the color and listen to the tone." As stated before, the individual tone-color pairs were presented at the rate of 5 per minute, or a total of 50 during the ten minute period constituting each series. Two or more series of 50 pairs of stimuli were often presented at the same sitting according to the amount of time the subject could devote to the experiment on that particular occasion.

The total number of presentations of the paired stimuli which would be required to establish the conditioned response, if at all, was of course unknown. Pavlov (19) and his co-workers have succeeded in conditioning dogs with as few as five repetitions of the stimuli, while the greatest number of repetitions required in any previously reported experiment was 400 in the case of the pupillary and eye-lid conditioning experiments of Cason. For the present experiment, it was felt that at least 2000 repetitions of the paired stimuli should be presented if a conditioned response was not established with fewer. It was, of course, almost a physical impossibility to present all of the 2000 stimuli at one sitting. Since it has been shown that interruption even for periods of months does not destroy a conditioned reflex, it did not seem that the presentation of the stimuli on successive days would seriously invalidate the experiment. In order to make sure that the spaced stimulations were not responsible for a failure of the response to become conditioned, the experimenter and another subject taking part in the group experiment subjected themselves to 1000 successive presentations of the eight pairs of stimuli at one sitting which lasted six and one-half hours. A similar test of the relative effect of spaced and concentrated stimulation was made for a single tone-color pair. Here again the experimenter and one other subject sat through 1000 repetitions of the stimuli. In this case the sitting lasted about three and one-half hours.

Subjects

A total of 18 subjects took part in the experiment. All were university students, mostly graduate students, and all had had one or more courses in psychology. Of the

18, thirteen were members of the group experiment utilizing the entire scale. The other five took part in the individual experiment with single tone-color pairs, and each was presented with at least 1000 repetitions of the paired stimuli. Since the group experiment required an exhorbitant amount of time from each subject and involved the inconvenience of meeting over a period of seven weeks, it was not possible for all of the 13 members of the group to continue through the course of the experiment. However, five of them were presented with at least 2000 repetitions of the stimuli, and one, the experimenter, experienced over 3000 stimulations. The remaining eight subjects were presented with from 280 to 1000 stimulations.

A series of preliminary tests and a questionnaire revealed the facts that: all of the subjects had normal color vision; all had an intrinsic interest in the problem; all were sceptical of the possibility of positive results; none of the subjects had any natural tendency toward chromaesthesia but one subject was synæsthetic to the extent of having number and date forms; and that the group represented an approximate chance selection with regard to artistic and musical ability. The results of a color and tone association test confirmed the above statement that the group was primarily non-synæsthetic.

Method of Ascertaining Results

The experiment as outlined above provided for two types of results: (1) an answer to the question of whether or not it is possible to produce chromæsthesia by the technique of the conditioned response (or whether chromæsthesia may result from the simple association of color and tone); and (2) the indication of any association learning which might have occurred. The major purpose of the experiment was, of course, to determine the possibility of conditioning chromæsthesia. While it was expected that a certain amount of associational learning would occur, this aspect of the experiment was incidental.

Since the experimental situation was such that both conditioning and learning might occur, it is necessary to set up certain criteria by which to interpret the results obtained. Although Pavlov (19) and others regard learning and conditioning as one and the same thing, the writer believes himself justified in making a distinction between the two processes in this case. It was to be expected that the simultaneous presentation of the stimulus pairs would result in a type of abstract learning of the paired tones and colors. Since only eight pairs of stimuli were used, it would have been but a simple matter for anyone with a good sense of pitch to memorize the colors corresponding to each of the tones. Since the tones were easily distinguishable by most of the subjects, it would have been surprising if they did not acquire the ability to name the color paired with any given tone. Obviously, this could not be taken to indicate the formation of a conditioned response, but merely the learning of paired associates.

By definition, the formation of a conditioned response requires that the substitute or conditioned stimulus become an adequate stimulus for eliciting the response formerly called forth by the unconditioned stimulus. In the present experiment, this response consisted in the seeing of colors. If the tones became capable of arousing spontaneous sensations or images of color in the subjects, then and only then, could it be said that a true conditioned response had been established.

Because of the non-overt nature of sensation, it was practically necessary to utilize the verbal reports of the subjects in determining the results of the experiment. In spite of the unreliability of introspective reports in general, it is believed that those obtained in this study were both valid and reliable. The subjects were all fairly mature and cognizant of the need of accurate reports. As was evidenced by their intensive and loyal coöperation, they were all interested in the outcome of the experiment. The type of introspection called for, that is, the mere report of the presence or absence of color sensation was extremely simple, and lastly, there was no reason to report falsely.

The method used for obtaining these verbal reports also permitted the measurement of the amount of associational learning that had occurred. Briefly, it was as follows: at the end of each Thursday evening session, each subject was provided with a copy of a mimeographed sheet containing 40 numbered blank spaces. The following instructions appeared at the top of the sheet and were read aloud by the experimenter:

Directions.—You will be presented with a series of forty tones made up of notes picked at random from the scale. After each note is sounded, you are to write in the color which goes with that tone. Use the first letter rather than the entire word for the names of the colors. If you have a real image or sensation of the color, put your response in the column marked 'color'; if you do not seem to see the color but think that you know what color goes with the tone sounded, put your response in the column marked 'know'; and finally if you neither see the color nor know what color goes with the tone, guess a color and write the name of the response in the column marked 'guess.' Do not omit any response. If you do not know, guess!

Following the reading of the instructions, a series of forty tones were sounded in random order. Each of the eight notes were thus presented five times. The subjects were asked to guess if they did not know the correct response on the assumption that a certain amount of learning might have occurred without the subject being aware of it. Since all subjects guessed when they did not know the correct answer, goodness of performance on each test could be expressed in terms of the number or per cent of correct responses and thus permit direct comparisons. This method also made possible the drawing of both individual and group learning curves.

Results

The results of the experiment with regard to the conditioning of chromæsthesia were entirely negative. Not one of the eighteen subjects acquired any tendency to see colors upon the presentation of the auditory stimuli. There was not a single response in the column marked 'color' on any of the test blanks. Indeed the subjects' interest in the outcome of the experiment was so great that had anyone of the subjects experienced a real color sensation on hearing the tones, it is likely that he would have announced the fact at once rather than waiting to write down the response in the proper column. Conditioning, in the sense that has been described above, simply did not occur.

With regard to the learning aspect of the experiment, an analysis of the subjects' performance on the weekly 40 item test indicated that something analogous to learning had taken place. The number of subjects taking each test,[3] the number of previous presentations of the stimuli, and the mean number of correct responses to the test are shown in Table 1. As will be readily seen, there is a tendency for the correct number of responses to increase with the number of repetitions

[3] It was, of course, impossible for the experimenter as a group subject to both administer and take these tests.

TABLE 1

RESULTS OF THE CHROMÆSTHESIA EXPERIMENT

Test No.	1	2	3	4	5	6
No. of stimuli	360	680	1000	1320	1640	2000
No. of subjects	8	9	7	4	4	4
Mean score	22.5	23 1	28.0	26.0	31.0	31.7

of the stimuli. In other words, a certain amount of learning did occur. Since there were 40 responses on each test and only seven different colors were used, mean scores of 5.7 would have resulted from sheer guessing. Since the means of all the tests, even of the first one, are considerable over this value, it indicates that a definite amount of learning did occur. When plotted, the graphs for both the group and for the individual members, resembled the typical learning curve.

Certain factors, however, make it doubtful that the increase in performance can be attributed solely to learning. For instance, the scores on test 1 ranged from 12 to 38 correct responses out of a possible 40. Even on the last test, after 2000 repetitions of the stimuli, the four scores were 22, 32, 33, and 40. Since there were only eight pairs of stimuli involved, it is obvious that something other than a lack of learning ability was responsible for the failure of all subjects to make perfect scores after the first few repetitions of the stimuli. The most likely factor was the inability to identify the eight tones. Such being the case, it is conceivable that the increase in ability to name the corresponding colors might be attributed to an improvement in the sense of absolute pitch. However, an absolute sense of pitch was not necessary to recognize the different tones, since as has been mentioned, certain secondary cues were present in the tonal stimuli.[4]

That the ability to name the colors corresponding to the various tones was not simply the result of learning is supported by the fact that the subject, who with the experimenter, sat through 1000 repetitions of the 8 tone-color pairs was able to respond correctly to but 17 tones out of a series of

[4] This suggests the desirability of conducting an experiment utilizing pure tones and paired stimuli to determine the possibility of improving the sense of absolute pitch.

40 presented at the end of the session. In this connection it is interesting to note that the experimenter, after having been subjected to over 3000 repetitions of the stimuli, 1000 of which were consecutive, and after having planned and executed the experiment, was able to respond with the correct color but 25 times out of 40. What could be better proof that he had not become chromæsthetic?

Supplementary Experiments

Although there was not the slightest evidence that any conditioning had occurred even after the thousands of repetitions of the stimuli, certain supplementary experiments seemed desirable before concluding that such conditioning was impossible. It was conceivable that a weak connection had been established which was not sufficiently strong to cause the appearance of introspectively observable colors upon the presentation of the sound stimuli. Two possible methods of facilitating or augmenting any such latent tendency seemed worthy of trial.

As was mentioned earlier in this paper, Fêrè (**6**) held that colored hearing was due to the particular tonus of the nervous system, produced either by drugs, fatigue, an unusual experience such as a bad fright, or other emotional disturbance. Although this opinion is not widely held, it was thought worthwhile to carry out the following simple experiment.

As on several previous occasions, the experimental room was darkened and the subjects told that two complete ascending and descending scales would be played without the colors being presented. They were instructed to gaze intently in the direction of the screen while noticing carefully for the appearance of any possible color sensations or images that might occur. Between the first and second series of tones, a blank pistol cartridge was fired. Since the shot was entirely unexpected by the subjects, this loud report produced a most admirable emotional disturbance, if the reactions and reports of the subjects were a valid indication. In spite of the disturbance, none of the subjects observed any color sensations upon hearing the series of tones presented immediately after the shot.

Likewise fatigue did not facilitate any tendency toward chromæsthesia. On several occasions, the writer listened to the tones late at night after an unusually tiresome day, and yet there was not the slightest appearance of color. As can well be imagined the writer and the subject who sat through the six and one-half hour session of 1000 consecutive stimulations were in a state of fatigue, and yet in spite of both the recency of the stimulation and the fatigued condition, color sensations did not result from hearing the auditory stimuli.

The use of certain drugs as facilitating agents seemed somewhat more promising. It has already been noted that Gautier (8), in 1843, reported that he had been able to produce temporary chromæsthesia by the use of hasheesh. Havelock Ellis (5) observed that one of the effects of the drug, mescal, was to produce a tendency toward synæsthesias of various kinds. In view of these and other reports, it was decided to study the influence of mescal in facilitating any possible 'latent chromæsthesia' that might have resulted from the extensive conditoning process. Since mescal [5] produces both colored imagery and, at the same time, effects a temporary tendency toward chromæsthesia, it was thought that it might enhance any basic tendency that had resulted from the conditioning process so that the connection would be observable in the imagery of the subjects. If any colors were seen when under the influence of mescal, and if any connection had been established between the tones and the colors, it was expected that the paired colors would appear on the sounding of the various tones. It seemed also possible that the colors might be aroused by the tones before they began to appear spontaneously. And finally, it seemed likely that in view of the enormous number of stimulations by colored squares, there would be a predominance of squares among the colored imagery seen by the subjects under the influence of the drug.

Because of the many unpleasant effects of the drug, the experimenter planned to take the mescal himself rather than to ask any of his subjects to do so. However, upon informing

[5] For an excellent account of the properties and psychological effects of this interesting drug see: Kluever, Heinrich, *Mescal: The Divine Plant and Its Psychological Effects*, pp. 111. Psychic Miniatures, No. 22. Kegan Paul, London 1928.

the four subjects who had continued throughout the experiment of his plans, he was surprised to find that they also wished to take part in this phase of the experiment. Accordingly, it was planned that the entire group of five should take mescal. Another engagement prevented one of the subjects being present on the day chosen for the experiment, so actually only three of the group subjects in addition to the experimenter took part in this procedure. It seemed desirable also that at least one of the five subjects who had been presented with single tone-color pairs should also take part in the mescal experiment. Luckily, the subject who with the experimenter had been stimulated with 1000 consecutive repetitions of the single tone-color pair (A-blue) volunteered his services in this connection. The actual taking of the mescal was carried out just one week after the last meeting of the experimental group and on the day following the just mentioned intensive study of the single tone color pair. It seemed likely, therefore that the effect of sitting through three and one-half hours of stimulation by the blue squares would surely be noticeable in the resulting imagery of the individual subject and the experimenter.

In all then, five subjects including the experimenter actually took part in the mescal experiment. Although standard doses of the drug had not been determined, the reports of previous investigators indicated that six buttone, or approximately 15 grams, would probably be sufficient to produce the desired imagery and yet not enough to be dangerous to life or health. The buttons were mashed with mortar and pestle to make ingestion reasonably easy, and were then swallowed with the aid of water. Three doses of 5 grams each were taken with the aid of about 8 ounces of water. The first dose was administered at 2:10 P.M., at which time each subject was provided with a notebook and instructed to keep a diary of his experiences. At 2:45 the subjects entered the dark room and a series of tone scales were presented. The second dose was administered at 3:10 followed by a second presentation of the tonal stimuli at 3:45 while the third and last dose was given at 4:10. Additional tests of the adequacy of the tones for eliciting color imagery were made at 5:15 and again at 7:45 P.M.

Inasmuch as the detailed description of the reactions and imagery of the five subjects are of no particular value in connection with the present investigation, they will not be reported here.[6] In the present connection, suffice it to say that all but one of the subjects were rewarded for their pains by gorgeous arrays of colored visions which compared favorably with those described by previous investigators of the so-called divine plant. For all but one, the shows were subjectively expensive, since all of the subjects except the experimenter suffered severe attacks of nausea. Unfortunately, the one subject who did not experience unusual imagery of any kind seemed to suffer more than anyone else. Even a fourth dose of 5 grams taken at 5:10 failed to produce any unusual imagery for this subject.

Here again, there was no evidence that any connection had been established between the colors and tones used in the experiment. In spite of the fact that a constant train of colors was passing in the imagery of the subjects, the tonal stimuli not only failed to arouse the colors with which they had been paired, but also failed to alter materially the imagery being experienced at the time. Likewise, the tones failed to arouse colored imagery before it began to appear spontaneously. Either the conditioning process had failed to build up a basic framework of chromæsthesia or else mescal did not facilitate the connections sufficiently to make it introspectively observable. The latter alternative seems unlikely, since the mescal did produce certain synæsthetic tendencies in all of the subjects reacting positively to the drug. The most marked combinations of sense fields seemed to be between vision and touch and between vision and kinæsthesia, although there was some tendency for all types of sensations to be colored. Two of the subjects even remarked about their colored pains.

The failure of the conditioning process to influence the mescal imagery was further indicated by an almost complete

[6] Kelly, E. L. *Individual Differences in the Effects of Mescal.* Jour. General Psych. 1933, 9, 462–472.

absence of colored squares in the imagery experienced by the subjects. Even the experimenter, who enjoyed an unusually beautiful array of colored images, observed no indication that the 1000 stimulations with the blue square on the previous day influenced his imagery in any way. There was simply no observable evidence of any kind that the subjects had engaged in the experiment for the past seven weeks. Thus we find that the use of mescal served only to emphasize the negative nature of the experimental findings.

IV. Interpretation of Results

We have seen that in spite of the extensive conditioning procedure and the seeming adequacy of the methods used to check the results of the experiment, there was not the slightest evidence to indicate that a conditioned response had been established. Artificial chromæsthesia was not produced in any of the subjects, and the mescal experiment failed to reveal any connections between tonal and visual stimuli used. As was stated in the beginning of this report, positive and negative results were equally desirable. Without question, the results turned out negative. They are so distinctly so that the writer has no hesitancy in concluding that it is impossible to produce chromæsthesis in normally non-synæsthetic adult subjects by the technique of the conditioned response.

A number of reasons might be suggested as to why a conditioned response of chromæsthesia was not established. First, it might be argued that the number of stimulations was not sufficiently large. However, in view of the fact that conditioned responses have been established by as few as five presentations of the stimuli and that in other cases it has not been necessary to use more than 400 repetitions, the thousands of stimuli used in this experiment seem unusually adequate. It is very unlikely that conditioning would have resulted had a larger number of stimulations been presented.

It might also be suggested that the spaced conditioning periods prevented the formation of the conditioned response. It will be remembered, however, that two subjects were given 1000 consecutive stimulations with no different results.

Again, it might be thought that conditioning failed to occur because of the inhibitory effect of the several pairs of stimuli used. This can hardly have been the case, since five subjects were presented with only a single tone-color pair, and there was no more evidence of conditioning than when the eight pairs of stimuli were used.

While other minor objections might be raised in regard to the experimental technique employed, the procedure appears to have been so nearly adequate that the reason for the failure to establish a conditioned response must be sought elsewhere. It will be recalled that the two requisites for the formation of a conditioned reflex (response) are: (1) There must be an existent reflex (response) which may be either an unconditioned or a conditioned one; and (2) the conditioned and unconditioned stimuli must occur simultaneously, or the conditioned must precede the unconditioned stimulus. Unquestionably the second condition was satisfied in the present experiment. On the other hand, it will be remembered that it was only assumed that we were dealing with an existent response, inasmuch as the seeing of color seems to be a response to the light waves which are perceived as color. The questionable nature of sensation has already been mentioned, and the Weiss-Warren controversy (24, 26) of a few years ago served only to emphasize the fact that we do not know whether sensation involves a somatic response as maintained by Weiss, or as Warren holds, consists only of a neural disturbance ending in the central nervous system.

A possible explanation, therefore, for the failure to establish a conditioned response of chromæsthesia is that there was no existent response to become conditioned. In other words, the negative results of the experiment might indicate that the perceiving of color is not a response. This interpretation fits in nicely with Warren's view of the cortical nature of sensation, and it seems to the writer to be the most logical explanation for the failure to obtain positive results in the present experiment. At least, we can conclude that sensation is not a response of the ordinary type which has been shown to be capable of being conditioned.

The bearing of this conclusion on the conditioned reflex theory of chromæsthesia is evident. If 3000 successive presentations of the tone and color stimuli failed to produce chromæsthesia in normally non-synæsthetic subjects, it can hardly be assumed that the chance simultaneous occurrences of visual and auditory stimuli in actual life could result in the marked cases of colored hearing which are occasionally encountered. Likewise the findings indicate the gross inadequacy of the psychical association theory of chromæsthesia.

Certain qualifications of these conclusions must be made. The present experiment showed that it is impossible to condition chromæsthesia in a group of adult subjects. It is conceivable, though hardly likely, that it might be possible to produce chromæsthesia in more youthful subjects by the conditioned response technique. It may be that such stimulations as occur during early childhood or under certain emotional strains may result in the cases of chromæsthesia which occur. The results of the present study, therefore, do not permit an all-inclusive denial of the conditioned reflex theory of chromæsthesia. It seems extremely desirable that a similar experiment be conducted with very young subjects and with subjects under severe emotional strain, in order to test the validity of the technique under these conditions.

Inasmuch as linkages between colors and tones of differing timbre are reported more often than linkages between colors and tones of specific frequencies it is conceivable that conditioning might have resulted from the use of tones widely different in quality, such as produced by different musical instruments. It does not seem likely that such positive results would have been achieved by these means, since there was no indication of conditioning even in the experiment employing single tone-color pairs.

For still another reason the writer holds that the conditioned reflex and psychical association theories are not adequate explanations of chromæsthesia. If, as they assume, the mere simultaneous occurrence of certain stimuli result in a tendency toward later double perception, why is it that marked cases of chromæsthesia are so rare? Certainly a large proportion of growing children are exposed to many simultaneously presented stimuli, yet only a very small number of cases of true chromæsthesia result. It seems, therefore, that there must exist, in a few persons at least, a predisposing physical or physiological basis which permits connections to be readily formed. Such a physical or physiological disposition might be either inborn or the result of somatic changes occurting during the life of the individual.

While the writer does not wish to propose a new theory of chromæsthesia, he does feel that some such hypothesis as the above must be incorporated in anything like an adequate explanation of the phenomenon. By assuming a physiological disposition plus a conditioning process, most of the known facts of chromæsthesia can be explained readily. The hereditary tendency of the trait as well as the wide idiosyncrasies which have been reported are thus reconciled in one explanation, a thing which all other theories have failed to do. Likewise the rarity of cases of chromæsthesia can be explained on the assumption that suitable predispositions are rarely existent upon which the conditioned response may become established.

The negative results of the present experiment are also quite explainable by such a theory. If the physiological predispositions necessary for the formation of the conditioned responses are rare, as is suggested above, it is not likely that one would have appeared in the relatively small group of subjects used in the experiment.

It has been argued by some that a purely physiological theory is sufficient without including the assumption that conditioning occurs. A crucial test of whether conditioning does supplement a physiological factor in the production of chromæsthesia could be made by attempting to destroy and change the color-tone associations in *bona fide* cases of colored hearing. If it could be shown that it is possible to experimentally destroy the linkages reported, it would offer almost incontrovertible evidence that conditioning had played a rôle in the production of synæsthesia. It was hoped that this experiment might be included in the present investigation but it was impossible to obtain a good case of chromæsthesia upon which to work. A newspaper appeal failed to locate a single case in the vicinity. Again we have an indication of the rarity of the phenomenon.

One other theoretical implication of the experimental findings should be mentioned. The negative nature of the results seem to indicate a limitation of the conditioned reflex-response technique, which has heretofore been considered by some (Watson, **25**) to be a tool of almost unlimited applicability. Since the results for both the group and single pairs of stimuli were negative, the data do not permit any conclusions as to the possibility of establishing a series of conditioned responses simultaneously. The results do suggest that it is not likely that the technique is going to permit a crossing-over of any two sense fields. Further experimentation, however, will be necessary before definite conclusions can be drawn in regard to either of these questions.

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References

1. Allen, F., The significance of reflex action in color vision, *British Medical Journal*, 1930, No. 3642, 683–684.
2. Argelander, A., *Das Farbenhören und der Synæsthetische Faktor der Wahrnehmung*, pp. 172, Gustav Fischer, Jena, 1927.
3. Carnaz, Ch. A., *Des Abnormites congenitales des jeus et de leurs années*, Lusanne, 1848 (Quoted by Krohn).
4. Cason, H. B., The conditioned pupillary reaction, *Journal of Experimental Psychology*, 1922, **5**, 108–146.
5. Ellis, Havelock, Mescal: A study of a divine plant, *Popular Science Monthly*, 1902, **61**, 52–71.
6. Fêrè, Ch., Sur les Affets Generaux des Excitations des Organs des Sens, *Le Bulletin Médical*, 1887, Nos. 83 and 87.
7. Galton, Sir Francis, *Inquiries into Human Faculty*.
8. Gautier, T., Le club des hachichiens, *La Presse*, July 10, 1843.
9. von Goethe, J. W., Zur Farbenlehre, *Naturw. Schriften*, 4Bd., 2 Abt.
10. Hoffman, L., *Versuche einer Geschichte der Malerischen Harmonie überhaupt*, Halle, 1786 (Quoted by Krohn).
11. Kaiser, H., Assoziation der Worte mit Farben, *Archiv. f. Augenheilkunde*, 1882, **11**, 96.
12. Krohn, W. O., Pseudo-chromæsthesia or the association of colors with words, letters, and sounds, *Amer. Jour. of Psych.*, 1892, **5**, 20–41.
13. Lewes, George H., *Problems of Life and Mind*, 3rd Series, Houghton, Osgood and Co., Boston, 1880, pp. 280–285.

14. LUNDBORG H., Die Vererbung des Farbenhörens und gewisser anderer psychische Eigenschaften innerhalb einer Schwedischen Geschlechts, *Act. med. Scand.*, 1923, **59**, 221–229.
15. LUSSANA, F., *Fisologia der colori*, Pandone, 1873 (Quoted by Krohn).
16. MAHLING, F., Das Problem der Audition Colorée, *Arch. f. d. ges. Psych.*, 1926, **57**, 165–301.
17. NUEL, J., *Dictionnaire Encyclopedique des Sciences Médicales*, Vol. 83, Article on Retina.
18. NUSSBAUMER, J. A., Über Subjektiv Farbenempfindungen usw., *Med. Wochenschrift*, Nos. 1, 2, and 3, Vienna.
19. PAVLOV, I. P., *Conditioned Reflexes*, Humphrey Milford, Oxford Press, 1927, pp. 430.
20. POUCHET AND TOURNEUX, *Precis d'Histologie Humaine et d'Histogenie*, 2nd Edition, 1878.
21. SCHENKL, A., Über Assoziation der Worte mit Farben, *Prag. Med. Wochenschrift*, 1883, **10**, 94, and **11**, 101.
22. STEVENS, J. S., Colors of letters, *Popular Science Monthly*, 1892, **40**, 697.
23. TITCHENER, E. B., *A Textbook of Psychology*, Macmillan, New York, 1921.
24. WARREN, H. C., Psychology of the central nervous system, *Psych. Rev.*, 1921, **28**, 249–269.
——, The significance of neural adjustment, *Psych. Rev.*, 1922, **29**, 481–489.
25. WATSON, J. B., The place of the conditioned reflex in psychology, *Psych. Rev.*, 1916, **23**, 89–116.
26. WEISS, A. P., Behaviorism and behavior, I and II, *Psych. Rev.*, 1924, **31**, 32–50, and 118–149.
27. WHEELER, R. H., The synæsthesia of a blind subject, *Univ. of Oregon Publications*, 1920, **1**, No. 5.
28. WOODWORTH, ROBERT S., *Psychology*, Revised Edition, Henry Holt and Company, New York, 1929.