THE EFFECT OF STIMULATION OF THE SENSES OF VISION, HEARING, TASTE, AND SMELL UPON THE SENSIBILITY OF THE ORGANS OF VISION

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HISTORICAL

It has long been known that the stimulation of one sense organ influences in some degree the sensitivity of the organs of another sense. But whether the influence is exerted upon the receptors or upon their central areas in the cortex has not been with certainty determined. This behavior of the nervous system may readily be inferred from its synaptical arrangement and internunciatory constitution whereby all parts are susceptible of communication with each other. These ideas have thus been summarized by Sherrington (12): "All parts of the nervous system are connected together and no part of it is probably ever capable of reaction without affecting and being affected by various other parts, and it is a system certainly never absolutely at rest."

The two senses which seem to be best adapted for the purpose of measurement are those of hearing and vision. As long ago as 1888, Urbantschitsch (13) observed that sounds of different tones may act differently upon the sensitivity of the visual apparatus for various colors, but no definite quantitative relation between sound and color was detected by him. In later investigations Lazarev (11) concluded that the visual sensibility of the retinal periphery, that is of rod vision, increased under the influence of acoustical stimulation of the ear. Yakovlev (15) found that stimulation of the ear by sound conspicuously enlarged the area of the field of cone vision especially for green light. Kravkov (8) observed that under the influence of sound the critical frequency of flicker of white light increases for central or cone vision, and diminishes for peripheral or rod vision.

In a recent investigation Yakovlev (16) has studied in much detail the influence of acoustic stimulation, both by musical tones of frequency 780 cycles per second and noises of 75 decibels in loudness, upon the limits of the areas of the retinal fields for extreme red, orange-red, green, and blue colors. The colors were not spectral but were obtained from Wratten color filters. The maximum transmissions of the filters were at 700 mμ, 680 mμ, 540 mμ, and 440 mμ respectively. Two observers were employed and from their measurements the following results were obtained. Under the influence of both tones and noises the color field for extreme red was unaltered, that for orange-red was diminished, and those for green and blue enlarged in area. Noise was more effective as a stimulus than musical tones, possibly because of its greater intensity, and under its influence the color fields were diminished and enlarged to the greatest extent.

In a more detailed research Kravkov (9) has investigated the influence of acoustic stimulation of the ear upon the light, or rod, and the color, or cone, sensibility of the visual apparatus. The experiments were performed with the right eye when both eyes were in darkness adaptation. An observer viewed in a spectrometer a small patch of some spectral color which was gradually diminished in intensity by means of an absorbing wedge of neutral tinted glass placed between the slit and the source of light. As the visual field gradually became darker, the observer first indicated the moment when color disappeared, and, second, when light vanished. The light and color thresholds or sensibilities were measured by the reciprocals of the thickness of the part of the wedge in front of the slit at the two positions. The experiments were continued for 1.5 hours, and during this period visual measurements were taken at intervals of from 8 to 13 minutes. After 40 minutes of darkness adaptation a condition of steady visual sensibility was assumed to have been attained, and then an acoustic stimulus, consisting of a musical tone of 2100 cycles per second and 100 decibels in intensity, from a generator of low frequency, was conveyed to both ears of the observer by a telephone receiver for a period of 10 minutes. While the sound was maintained the visual measurements were repeated. At the end of this period the sound was stopped and the measurements were continued as at first. It was found by three observers of normal vision that light (rod) sensibility, contrary to Lazarev's finding, was greatly diminished under the influence of sound. For the colors green and orange-red opposite results were obtained. The sensibility for green (528 mμ) was raised and that for orange-red (610 mμ) was lowered.

The wave-length 560 mμ divides the two effects. For orange-red colors greater than this wave-length the sensibility of the visual apparatus was diminished. For green and blue colors shorter than this intermediate wave-length the sensibility was increased. The ends of the spectrum beyond the wave-lengths 460 mμ and 620 mμ were not observed.

The contradiction between Lazarev's and Kravkov's findings for light, or rod, sensibility may be due to the fact that the observations of the former were made upon the retinal periphery and those of the latter upon the macula. If both sets of observations are correct it follows that the macular and peripheral rods respond in opposite ways to threshold intensities of stimulation.

The Present Investigations

In the present investigations the writers have confirmed the work of Kravkov on the influence of hearing upon color vision, and in addition they have studied the effect of stimulation of the senses of taste and smell upon the perception of colors. They have also extended the observations to include the oscillation of sensitivity of the sensations of vision which results from stimulation of the senses of vision, hearing, taste, and smell.

For convenience of investigation the critical frequency of flicker of the colors of the spectrum was observed before and after the stimulation of the other senses. By comparing the measurements obtained under both conditions, the influence of the other senses upon vision was determined.

The method of experimentation was as follows: A spectrum was obtained from an incandescent lamp of 75 watts which was kept at a steady brightness by a fine rheostat with a voltmeter placed across the terminals of the lamp to insure a constant potential difference. A Hilger spectrometer with the equivalent of three 60° prisms gave a spectrum of wide dispersion, a small portion of which of any desired wave-length was isolated in the eyepiece by adjustable shutters. Between the lamp and the slit a sectored disk was rotated by an electric motor whose speed was controlled by a leather brake resting upon the axle. To the rear end of the axle was attached a speed-counter which made electric contact every fiftieth rotation of the armature and disk, and the moment of contact was recorded on a strip of paper on a chronograph simultaneously with time indications from a clock beating half-seconds. By measuring these two records, the time of rotation of the disk, and hence the duration of a flash of color upon the retina at its critical frequency of flicker was accurately determined. In making a normal graph of the spectrum for purposes of comparison with those obtained after stimulation of the other sense organs, the eyes were kept adapted to ordinary daylight illumination of the room between the hours of 10 a.m. and 3 p.m. A selected patch of the spectrum whose wave-length was obtained from the calibration curve was viewed in the eyepiece, the disk was rapidly increased in rotation until the critical frequency of flicker was reached, and while this speed was maintained steady by the brake, the record was made upon the chronograph. The sense of hearing, taste or smell, or vision itself, was then adequately stimulated for 2 minutes and the measurements of the critical frequency were repeated immediately or after various intervals of time. This procedure was repeated for colors throughout the spectrum. The graphs for the normal and induced states of vision were then drawn together, as shown in the figures, and from their differences the effect of stimulation of any sense organ upon vision was determined. Since the physical brightness of the spectrum remained unchanged, the differences between the two graphs reveal the physiological changes in brightness, whether increased or diminished, and hence the alterations in responsiveness or sensitivity of the visual sensations, which stimulation of another sense had induced.

The Effect of Stimulation of the Retina upon Color Vision

In making the measurements the normal curve for the critical frequency of flicker was first obtained for the right eye when both eyes were in daylight adaptation. The measurements were then repeated throughout the spectrum with the right eye in constant adaptation for red or yellow light of wave-lengths 687 $m\mu$ and 589 $m\mu$. This condition was maintained by stimulating the retina with the red color from a second spectrometer for 2 minutes before each observation of the critical frequency of flicker was taken. Two sets of measurements were made; one, when no rest interval was taken, and, second, when a rest interval of 3 minutes was allowed between the termination of stimulation of the retina and the reading of the critical frequency of flicker. In all other respects the conditions of experiment were alike.

The measurements are given in Table I, and those for the normal and for stimulation by yellow light with no rest interval are shown in graphical form in Fig. 1. The normal is the broken line. The horizontal scale represents wave-lengths and the ordinates are the values of the duration of a flash of light upon the retina at the critical frequency of flicker, or the equal interval of time during which no light is seen. The persistence of vision carries the impression of one flash of color over the dark interval with no appearance of interruption.

The differences between the two graphs are also shown more clearly in the lower part of Fig. 1. The normal graph is represented by the straight broken horizontal line, and the differences between the two sets of measurements by the continuous line. It is known that the brighter the light the shorter is the duration of stimulation at the critical frequency of flicker. The elevation of the continuous line above the normal, therefore, indicates that the corresponding colors are perceived with diminished brightness, and its depression below the normal shows that the corresponding colors appear enhanced in brightness.

TABLE I

Wave-length	Normal	Stimulation with λ 589 mμ. Rest period = 0		Stimulation with λ 589 mμ. Rest period = 3 min.		Stimulation with λ 687 mμ. Rest period = 0		Stimulation with λ 687 mμ. Rest period = 3 min.	
mμ	*sec.*	*sec.*	*diff.*	*sec.*	*diff.*	*sec.*	*diff.*	*sec.*	*diff.*
720	0.0138	0.0143	+5	0.0134	−4	0.0143	+5	0.0134	−4
700	0.0125	0.0129	4	0.0122	−3	0.0130	5	0.0122	−3
680	0.0116	0.0119	3	0.0113	−3	0.0118	2	0.0114	−2
660	0.0112	0.0112	0	0.0109	−3	0.0112	0	0.0112	0
640	0.0109	0.0109	0	0.0108	−1	0.0107	−2	0.0112	+3
620	0.0107	0.0111	4	0.0105	−2	0.0103	−4	0.0110	3
590	0.0106	0.0112	6	0.0102	−4	0.0101	−5	0.0112	6
550	0.0114	0.0117	3	0.0106	−8	0.0111	−3	0.0117	3
530	0.0119	0.0122	3	0.0113	−6	0.0116	−3	0.0120	1
500	0.0134	0.0132	−2	0.0136	+2	0.0132	−2	0.0137	3
480	0.0156	0.0151	−5	0.0160	4	0.0153	−3	0.0159	3
465	0.0175	0.0169	−6	0.0180	5				

The graphs for stimulation by red light of wave-length 687 mμ, with no rest interval and with a rest period of 3 minutes are shown in Fig. 2 A and 2 B. There is revealed in the latter a complete reversal of the effects of stimulation shown in the former. For the latter graph indicates that the red color is now increased in brightness and the green and violet colors diminished. In other words, the immediate influence of stimulation by red light is to depress the red and enhance the green and violet sensations; while during a rest period of 3 minutes the neural reactions have completely reversed the responsiveness of the sensory apparatus, so that the red sensation becomes enhanced and the green and violet sensations are depressed in sensitivity.

After stimulation by yellow spectral light of wave-length 589 mμ, similar measurements were made with no rest interval and after one of 3

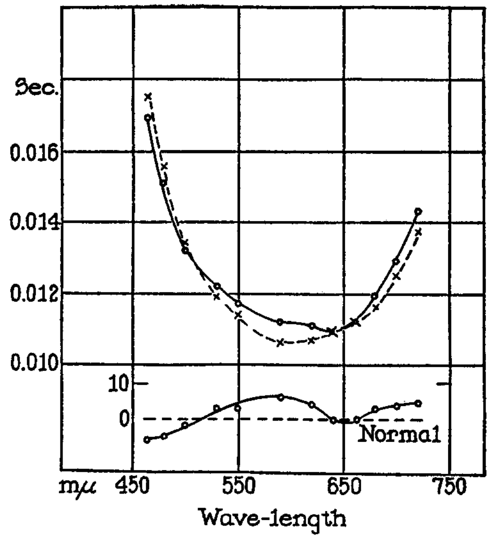

FIG. 1. Effect of stimulation of the retina with yellow light, wave-length 589 mμ, for 2 minutes. No rest interval. The normal graph for the unstimulated retina is the broken line. The lower graph represents differences between the two graphs above.

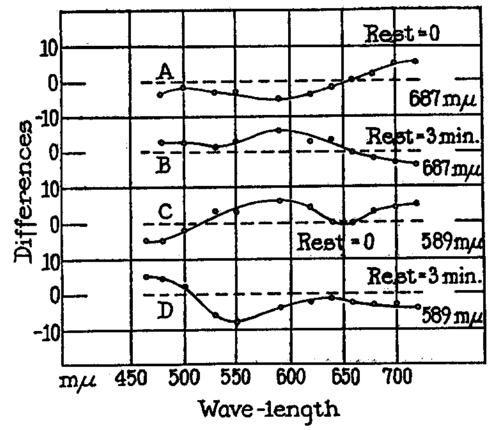

FIG. 2. Effects of no rest interval and of one of 3 minutes after stimulation with red (687 mμ) and yellow light (589 mμ). The effect of rest is to reverse the immediate effect of stimulation. The broken line is the normal.

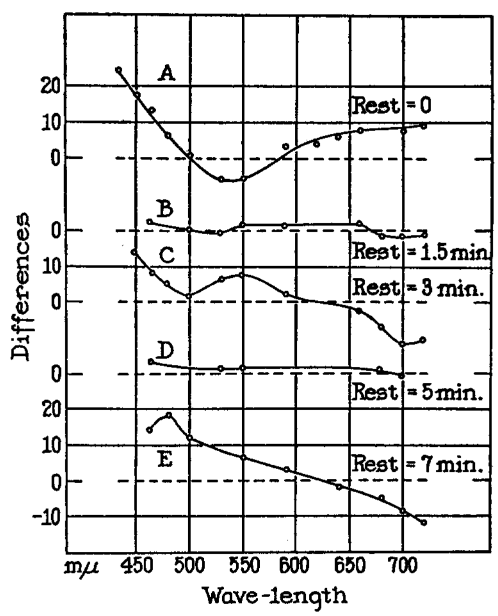

FIG. 3. Visual effect of stimulating the ear with tones of 150 cycles per second, after various rest periods from 0 to 7 minutes. The broken line is the normal.

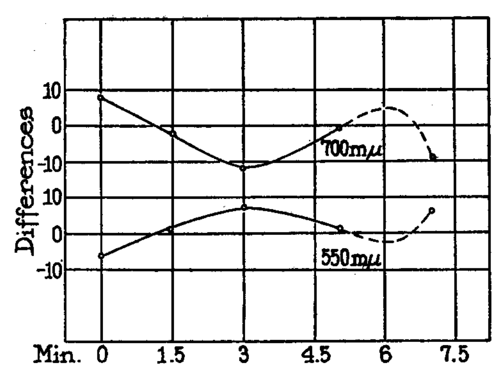

FIG. 4. Oscillation of visual sensitivity after stimulation of the ear by sound. Abscissae are rest periods. Ordinates are differences between normal values of the critical frequency of flicker and the values after various periods of rest. The lines at zero represent normal values.

minutes duration. The data are also given in Table I. The former are shown in Fig. 1 as just described, and they are both shown in the two lower graphs, C and D, in Fig. 2. As the yellow sensation is compounded of the red and green sensations, the graph for no rest interval shows that these sensations have been diminished in sensitivity and the violet has been enhanced by direct stimulation. When rest intervals of 3 minutes were taken after stimulation before readings of the critical frequency of flicker were made, the sensitivities of the sensations were reversed. These reversals occurred through the influence of internal reactions alone.

These observations, as far as the immediate effects obtained with no rest intervals are concerned, confirm the findings of Allen (1) in former investigations.

The Visual Effect of Stimulation of the Sense of Hearing

The influence of stimulation of the sense of hearing upon vision, with which this investigation started, will now be described. For the purpose of stimulation of the ear a Stern Tonvariator was used. This is a Koenig resonator with the bottom like a piston which can be moved inwards to produce a pure tone of any frequency within one octave. The tone, which is generated by blowing a stream of air obliquely across the orifice at the top of the tonvariator, is very pure and free from overtones. In the present investigation two instruments were used, one giving a tone of 150 and the other 1200 cycles per second. Two intensities were used, one given by air pressure of 2 cm. of water and the other by 2 mm. of water. The right ear was held very close to the orifice where the sound was generated, and thus a tone of fairly high intensity was directed into it. The tone given by the lower pressure was very weak. The left ear of the observer was protected from sound by a tuft of cotton wool inserted in the passage, though this precaution, under the conditions of stimulation, was found to be unnecessary.

In making observations the procedure was invariable. The normal curve for the critical frequency of flicker was first obtained by the right eye when the eyes and ears were in normal unstimulated condition, or, more accurately, when both organs were adapted to the daylight and sounds of an ordinarily quiet room. The right ear was then stimulated by the sound for 2 minutes and the readings of the critical frequency of flicker immediately taken. After readjustment of the instruments the aural stimulation was renewed, followed again by the visual measurements. This procedure was repeated until observations were made over the spectrum. The tonvariator was placed near the flicker apparatus so that the observer could turn immediately from one to the other. Sets of measurements were made with no rest interval, and with rest intervals of 1.5, 3, 5, and 7 minutes between the termination of aural stimulation and the visual observation. The data are given in Table II and are shown graphically in Fig. 3. As before, the broken horizontal lines represent the normal curves, and the continuous lines those for the critical frequency of flicker after aural stimulation. Again, elevations and depressions of the continuous lines indicate respectively diminished and enhanced conditions

TABLE II

Visual Effect of Stimulation of the Sense of Hearing. Stimulation of Right Ear

Wave-length	Normal	Rest period = 0 min.		Rest period = 1.5 min.		Rest period = 3 min.		Rest period = 5 min.		Rest period = 7 min.	
mμ	*sec.*	*sec.*	*diff.*	*sec.*	*diff.*	*sec.*	*diff.*	*sec.*	*diff.*	*sec.*	*diff.*
740	0.0194										
720	0.0170	0.0179	+9	0.0169	−1	0.0159	−11			0.0158	−12
700	0.0150	0.0158	8	0.0148	−2	0.0138	−12	0.0149	−1	0.0141	−9
680	0.0132	—	—	0.0130	−2	0.0125	−7	0.0133	+1	0.0127	−5
660	0.0121	0.0129	+8	0.0123	+2	0.0118	−3	—		—	
640	0.0116	0.0122	+6	—	—	—	—	—		0.0114	−2
620	0.0112	0.0116	+4	—	—	—	—	—		—	
590	0.0106	0.0109	+3	0.0107	+1	0.0108	+2	—		0.0108	+2
550	0.0112	0.0106	−6	0.0113	+1	0.0119	+7	0.0113	+1	0.0118	+6
530	0.0118	0.0112	−6	0.0117	−1	0.0124	+6	0.0119	+1	—	
500	0.0131	0.0132	+1	0.0131	0	0.0132	+1	—		0.0143	+12
480	0.0148	0.0154	+6	—	—	0.0153	+5	—		0.0166	+18
465	0.0165	0.0178	+13	0.0167	+2	0.0173	+8	0.0167	+2	0.0179	+14
450	0.0187	0.0204	+17			0.0201	+14				
435	0.0216	0.0240	+24								

In all cases frequency = 150 vibrations or cycles per sec.
Tonvariator pressure = 2 cm. of water.
Stimulation period = 2 min.

of the brightness of the corresponding colors, which are due to similar changes in the responsiveness of the fundamental color sensations.

The graph in Fig. 3 A, for no rest interval, indicates that the red color of the spectrum appears of lowered intensity, the green of enhanced, and the violet of lowered intensity. This result confirms the experiments of Kravkov, with aural stimulation of 100 decibels in loudness, for red and green colors. He did not carry his measurements into the blue and violet regions. With a rest interval of 1.5 minutes, the graph (Fig. 3 B) shows that the measurements of the critical frequency of flicker are almost of normal value but with a slight indication of a reversal of the condition represented by Fig. 3 A. When a rest interval of 3 minutes was taken, the graph (Fig. 3 C) reveals that a complete reversal of sensitivity of the red and green sensations has occurred, the red color now appearing brighter and the green dimmer than normal. With aural stimulation, the blue and

TABLE III

Visual Effect of Stimulation of the Sense of Hearing

Wave-length	Normal	Stimulus frequency = 150 cycles per sec. Pressure = 2 cm. Right ear		Stimulus frequency = 150 cycles per sec. Pressure = 2 mm. Right ear		Stimulus frequency = 150 cycles per sec. Pressure = 2 cm. Left ear.	
mμ	*sec.*	*sec.*	*diff.*	*sec.*	*diff.*	*sec.*	*diff.*
740	0.0194			0.0197	+3		
720	0.0170	0.0179	+9	0.0163	−7	0.0166	−4
700	0.0150	0.0158	+8	0.0138	−12	0.0145	−5
680	0.0132	—		0.0127	−5	0.0126	−6
660	0.0121	0.0129	+8	0.0121	0		
640	0.0116	0.0122	+6	0.0118	+2		
620	0.0112	0.0116	+4	0.0115	+3		
590	0.0106	0.0109	+3	0.0111	+5		
550	0.0112	0.0106	−6	0.0115	+3	0.0106	−6
530	0.0118	0.0112	−6	0.0119	+1	0.0113	−5
500	0.0131	0.0132	+1	0.0132	+1		
480	0.0148	0.0154	+6	0.0150	+2		
465	0.0165	0.0178	+13	0.0163	−2		
450	0.0187	0.0204	+17	0.0184	−3		
435	0.0216	0.0240	+24				

Wave-length	Normal	Stimulus frequency = 1200 cycles per sec. Pressure = 2 cm. Right ear		Stimulus frequency = 1200 cycles per sec. Pressure = 2 mm. Right ear	
mμ	*sec.*	*sec.*	*diff.*	*sec.*	*diff.*
740	0.0181	0.0202	+21		
720	0.0166				
700	0.0144	0.0155	+11		
680	0.0134				
660	0.0125	0.0131	+6	0.0128	+3
640	0.0122				
620	0.0114	0.0119	+5	0.0119	+5
590	0.0109	0.0113	+4		
550	0.0118	0.0112	−6	0.0112	−6
530	0.0125	0.0117	−8	0.0116	−9
500	0.0144	0.0135	−9		
480	0.0163	0.0165	+2	0.0159	−4
465	0.0184	0.0187	+3		

violet colors experience no reversal in brightness. After a rest interval of 5 minutes, the brightness of the spectrum, as shown by Fig. 3 D, appears of normal value. When the rest interval was increased to 7 minutes (Fig. 3 E) the curve indicates much the same changes in color intensities as shown in Fig. 3 C for 3 minutes of rest.

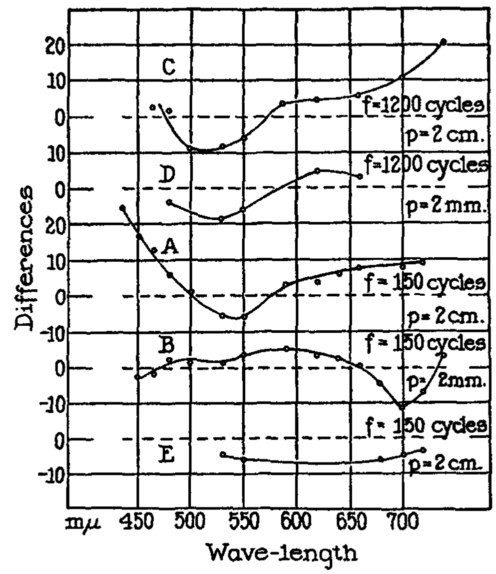

FIG. 5. Visual effects of aural stimulation by tones of different frequencies and intensities. Graph E is contralateral effect of aural stimulation. The broken lines are the normals.

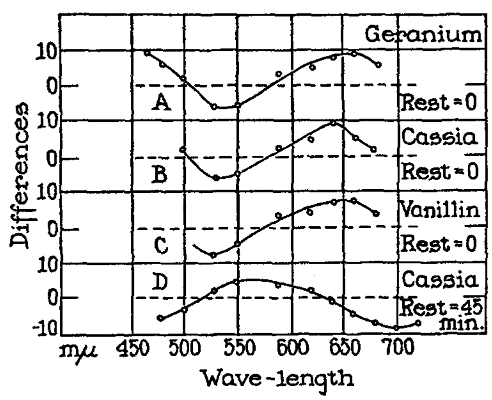

FIG. 6. Visual effect of olfactory stimulation with various substances, after no rest periods and after 45 minutes of rest. The last shows reversal of effect. The broken lines are the normals.

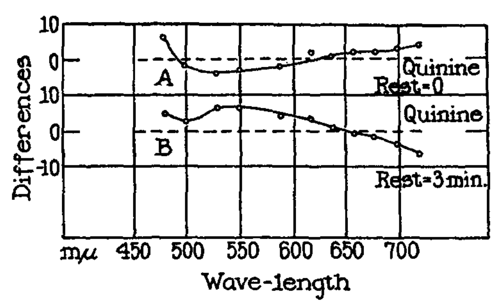

FIG. 7. Visual effect of gustatory stimulation with solution of quinine sulfate, after no rest period and after 3 minutes. Reversal of effect is shown. Broken lines are normals.

Thus by internal reactions alone which are inherent somewhere in the visual apparatus, reversals of sensitivity of the visual organs occur in a definite oscillatory manner. By plotting cross-sections of the five curves in Fig. 3, the oscillatory effect is more strikingly displayed. This has been done in Fig. 4 for the wave-lengths 700 mμ, and 550 mμ. It will be noticed that the oscillations of sensitivity of the red and green sensations are opposite in phase.

In order to study the influence of aural stimulation of different intensities, a graph was obtained after stimulation by a weak tone of 150 cycles per second, produced by a low pressure of only 2 mm. of water. The data are given in Table III, and are plotted in Fig. 5 B in contrast with Fig. 5 A which is a repetition of Fig. 3 A for 150 cycles per second and a pressure of 2 cm. It will be seen that aural stimulation by the weaker tone has evoked a reversal of the visual effect caused by the louder tone of the same frequency, including, in this case, the violet end of the spectrum.

With aural stimulation by a high-pitched tone of 1200 cycles per second of strong and weak intensities given by air pressures of 2 cm. and 2 mm. of water respectively, the visual effects were those shown in Fig. 5 C and 5 D. These graphs are plotted from the measurements in Table III. They both show depression of sensitivity of the red and probably of the violet sensations, but enhancement of the green. There is no evidence of reversal of visual sensitivity under the influence of the weaker tone. It is possible that for the higher and more piercing tones, a still lower intensity than that obtained with a pressure of 2 mm. of water is required to evoke reversals of visual sensitivities, or else with stimulation by very high tones only depression of sensitivity occurs.

A few readings were obtained to show the contralateral influence of aural stimulation of the left ear upon the right eye. The measurements are given in Table III, and shown graphically in Fig. 5 E. All colors in the range observed from 530 mμ to 720 mμ are seen to be enhanced in brightness.

The Visual Effect of Stimulation of the Sense of Smell

In order to study the influence of stimulation of the sense of smell upon color vision, a volatile odorous material was placed in a bottle through the rubber stopper of which two glass tubes were passed. One of them dipped below the surface of the liquid. A current of air was then gently blown through it which conveyed a steady stream of odorous material through the second tube to the right nostril. The sense of smell was then stimulated by the odor for 2 minutes and readings of the critical frequency of flicker taken immediately afterwards with no rest interval. Three substances were used, oil of African geranium, oil of cassia, and an alcoholic solution of vanillin, all of which gave the same result. The measurements are given in Table IV and are plotted in Fig. 6, A, B, and C, respectively. With the odor of oil of geranium as the stimulating substance, the red and violet sensations, as shown in Fig. 6 A, were depressed in sensitivity and the green enhanced. With the other two substances the measurements gave similar results except that they were not extended into the blue-violet region of the spectrum.

TABLE IV

Visual Effect of Stimulation of the Sense of Smell

Wave-length	Normal	Stimulation with oil of geranium. Rest interval = 0		Stimulation with oil of cassia. Rest interval = 0		Stimulation with vanillin. Rest interval = 0	
mμ	*sec.*	*sec.*	*diff.*	*sec.*	*diff.*	*sec.*	*diff.*
680	0.0134	0.0140	+6	0.0136	+2	0.0138	+4
660	0.0125	0.0134	+9	0.0130	+5	0.0132	+7
640	0.0119	0.0127	+8	0.0128	+9	0.0126	+7
620	0.0114	0.0119	+5	0.0119	+5	0.0118	+4
590	0.0111	0.0114	+3	0.0114	+3	0.0114	+3
550	0.0117	0.0112	−5	0.0112	−5	0.0112	−5
530	0.0125	0.0119	−6	0.0119	−6	0.0117	−8
500	0.0148	0.0150	+2	0.0150	+2		
480	0.0169	0.0175	+6				
465	0.0185	0.0194	+9				
Wave-length	Normal	Stimulation with oil of cassia. Rest interval = 45 min.		Wave-length	Normal	Stimulation with oil of cassia. Rest interval = 45 min.	
mμ	*sec.*	*sec.*	*diff.*	*mμ*	*sec.*	*sec.*	*diff.*
720	0.0138	0.0131	−7	590	0.0091	0.0095	+4
700	0.0125	0.0117	−8	550	0.0097	0.0102	+5
680	0.0113	0.0106	−7	530	0.0102	0.0104	+2
660	0.0106	0.0102	−4	500	0.0117	0.0114	−3
640	0.0100	0.0099	−1	480	0.0130	0.0125	−5
620	0.0094	0.0097	+3				

A number of attempts were made, but without success, to discover whether, with various short rest periods up to 15 minutes, any reversal of color sensitivities occurred as a result of ipsilateral olfactory stimulation. Since in many ways the sense of smell is rather sluggish, it was decided to allow a rest interval of from 40 to 50 minutes after stimulation with the odor of oil of cassia before measurements of the critical frequency of flicker were made. The result showed (Fig. 6 D) that in the prolonged rest interval a decided reversal of sensitivity of all three color sensations occurred. As the graph indicates, the red and violet sensations are enhanced and the green depressed in sensitivity.

The Visual Effect of Stimulation of the Sense of Taste

Two sets of measurements after stimulation of the sense of taste were made, in both of which the stimulating substance was an aqueous solution of sulfate of quinine. This substance was chosen so that the bitter sensation, which is much the most sensitive of the four taste sensations, would be stimulated. A piece of absorbent cotton was soaked in this solution and placed on the back of the tongue for 2 minutes, then it was removed and the reading of the critical frequency of flicker taken. The mouth was then rinsed with water and the stimulation repeated with a fresh piece of cotton. In the first case no rest interval, and, in the second, a rest

TABLE V

Visual Effect of Stimulation of the Sense of Taste

Wave-length	Normal	Stimulation with quinine sulfate. Rest interval = 0		Stimulation with quinine sulfate. Rest interval = 3 min.	
mμ	*sec.*	*sec.*	*diff.*	*sec.*	*diff.*
720	0.0144	0.0148	+4	0.0137	−7
700	0.0128	0.0131	+3	0.0124	−4
680	0.0115	0.0117	+2	0.0113	−2
660	0.0109	0.0111	+2	0.0108	−1
640	0.0104	0.0105	+1	0.0104	0
620	0.0100	0.0102	+2	0.0103	+3
590	0.0099	0.0097	−2	0.0103	+4
550	0.0105	0.0102	−3	0.0111	+6
530	0.0110	0.0106	−4	0.0116	+6
500	0.0122	0.0120	−2	0.0124	+2
480	0.0134	0.0140	+6	0.0139	+5

interval of 3 minutes was allowed between the cessation of stimulation and the measurement of the critical frequency of flicker. The readings are given in Table V and are shown graphically in Fig. 7 A and 7 B. With no rest interval the red sensation is depressed and the green enhanced in sensitivity, while after a rest period of 3 minutes a reversal occurred in which the red sensation was enhanced and the green depressed in sensitivity. In both cases the violet sensation appears to suffer depression of sensitivity.

It may be remarked that stimulation with a solution of sugar was tried but with no apparent visual effect. The sweet sensation is, however, the most insensitive of the four gustatory sensations. Possibly a solution of saccharine might have been successful as a stimulant to produce a change of visual sensitivity.

DISCUSSION OF RESULTS

There is in the human body a wide-spread system of nervous channels through which certain effects of stimulation of one organ are conveyed to other organs both similar and dissimilar in character. One of the writers (6) has shown that stimulation of the right foot by a forward pressure against a wall diminishes the magnitude of the post-contraction muscular reflex in the right arm. This is a case of partial ipsilateral inhibition. The opposite effect had previously been investigated by Whisler (14) in a specially complete manner. In his researches he employed the post-contraction of the left leg as the normal response. Immediately after stimulation of the left arm, he found that the responses of the left leg were augmented. He then stimulated both arms simultaneously and found a greater augmentation of the subsequent response of the leg. The preliminary stimulation was then extended to include at once both arms and the right leg, with still greater augmentation of the response of the left leg. Finally, with these three he included stimulation of the muscles of the neck, and obtained the greatest degree of augmentation of the response of the left leg. Similarly, stimulation of different organs by faradic currents, pictures, music, and colors was followed by augmented post-contraction responses of the left leg.

The influence of various types of stimulation upon glandular secretion has been studied by several investigators. Thermal stimulation of the mouth above 55°C. and below 15°C., was found to be effective in exciting the salivary glands to increased activity. Lashley (10) observed that violent chewing of a tasteless substance such as rubber, elicited a very large increase in the amount of saliva secreted. Activity of the salivary glands is also greatly promoted by acids, alkalis, and salts held in the mouth, and also by many kinds of food especially when they are present in the stomach. Mental work also enhances the activity of glandular organs of several types. Inhibitory influences upon the salivary glands arise from violent effort, rapid movement, and prolonged strain. Most people are aware of the dryness of the mouth which occurs in running, in games such as football and tennis, and in athletic sports generally; and it is a common practice to counteract the inhibition of the salivary glands thus produced by the enhancing action of the chewing reflex promoted by the use of gum. Lashley found no salivary influence exerted by visual, auditory, or tactile stimulation under the conditions of his experiments.

Muscular fatigue may depress the memory, while excitement and apprehension are often found to enhance it. Impassioned emotional states have widespread physical effects. Fear inhibits the flow of saliva as many an inexperienced speaker has found to his discomfiture. Hunger, which is due to the muscular contraction of the stomach, induces weakness of the knees. Many additional instances of the influence of stimulation of one part of the organism upon the responses of other parts can no doubt be found.

In nerves themselves Erlanger and Gasser (7) have found evidence of an oscillation in excitability. After a nerve fibre has been excited by electrical stimulation, the threshold of response falls to a steady state through a series of three oscillations of diminishing amplitudes in which the threshold values are alternately lowered and raised. The period of these oscillations, 0.005 second, is, however, of an order of magnitude much different from those of 3 minutes which are described in this communication. The two values are perhaps scarcely comparable, since the short period oscillations are those of a single nerve fibre, while the long period oscillations are concerned with large numbers of fibres, their receptors, and their cortical terminations.

1. In the present investigation the writers have brought forward evidence of a precise character to show how stimulation of three sense organs influences the responsiveness of vision. It is found that stimulation with red light, sound, quinine, and odors produces by its immediate action much the same effect upon vision, which is the depression of the red sensation and the enhancement of the green; the violet sensation for some reason being sometimes depressed and at other times enhanced in sensitivity. The magnitude of the visual effect seems in all cases to be about the same. Since stimulation of various senses demonstrably affects vision, stimulation of the eyes probably reciprocally affects those senses. Perhaps all sense organs are so interrelated that stimulation of any one of them influences all others either by enhancing or depressing their responsiveness. It cannot therefore be maintained that the sense modalities are wholly independent of each other. While the validity of Müller's law of "specific energy" is not impugned, some modifying power upon the quality of response of one organ is nevertheless exerted by stimulation of other sensory receptors.

2. An examination of the graphs presented above shows that stimulation of each of the senses selected for experimentation has affected the responsiveness of the visual organs in the three parts by which the colors, red, green, and violet, are perceived. These results afford, therefore, a striking confirmation of the provisions of Young's tricomponent theory of color vision which postulates the existence of three fundamental color

sensations, red, green, and violet. It is further shown that these primary sensations are not independent of each other and that they are not all affected in the same way. For while the red sensation is depressed in sensitivity, the green is enhanced. It seems to be impossible to stimulate or influence in any manner a single color sensation alone.

3. It is shown also in the case of stimulation of the ear, that the intensity of the stimulus may be a determining factor in producing enhancement or depression of the sensitivity of the visual sensations. For it was found that loud and weak tones of the same low pitch evoked opposite conditions of responsiveness in the organ of vision. Also, it was shown that stimulation of the left ear evoked an enhanced visual response in the right eye. It was formerly demonstrated by Allen (2), Hollenberg (3), and Weinberg (5) that weak and strong stimulation of the senses of vision, touch, and taste similarly produced opposite effects on the sensibility of the organs directly involved.

4. One of the most outstanding characteristics of the graphs under discussion is the reversal of sensitivity of the visual sensations which they reveal as apparently a function of the duration of the interval of rest between the termination of stimulation of any sense organ and the measurement of the critical frequency of flicker. While in the experiments described in this communication the organ of vision is the only one tested for the oscillatory effect, it is doubtless the case that all the sense organs possess the same remarkable character. This oscillation of responsiveness has been shown by Allen and O'Donoghue (4) to occur in the post-contraction of the arm after both ipsilateral and contralateral stimulation. It seems to be the case, therefore, that when stimulation of any part of the organism occurs, the responsiveness not only of that part but also of all other parts neurally connected with it is disturbed, and the normal resting equilibrium is restored by a short series of oscillations of sensitivity in which the organs are alternately depressed and enhanced in responsiveness or excitability. Though the oscillation appears as a function of time, it is probably a cellular or molecular condition of the central areas that fluctuates in activity.

Since the responsiveness of the sense of vision oscillates after stimulation has occurred, the character of observations or measurements made in such circumstances would appear to depend on the time which has elapsed after the termination of stimulation; or, in other words, on the phase of oscillation which is predominant at the moment. By neglecting this factor, many contradictory observations in experimental investigations in color vision have doubtless occurred.

5. In the study of conditioned reflexes it has been found that new reflexes can be gradually substituted for habitual or unconditioned ones on a very exact and extensive scale. Those reflexes have demonstrated the existence of unused neural channels which connect the cortical areas and to some extent new activities have been built upon them. While much knowledge has been acquired concerning the character of these reflexes and the manner of establishing them, little seems to be known of the neural mechanisms upon which they are founded. The present investigation seems to deal with those modes of behavior of the central organs which lie at the basis of conditioned reflexes. The cerebral cortex has been described by Myers as a vast unravelled complex. The present experiments on the reciprocal actions of central areas seem to constitute an additional method by which material progress can be made in the unravelling process.

6. It may be safely inferred that stimulation of any sense organ influences all other sense organs in their excitability. There results, in consequence, an oscillatory condition of sensitivity which changes in state in each case by internal reactions governed by the lapse of time. The field of consciousness, to the extent in which it is based on the fluctuating responses of a delicately interlocked system of the senses, can scarcely remain constant under the ceaseless impact upon it of stimuli arising from the outer world and from the organism itself. These requirements, therefore, afford some physiological basis for the widely accepted Gestalt system of psychology, in which sensory presentations are not to be regarded as the narrowly restricted phenomena of individual organs, but as perceptual patterns where now one and then another sensation predominates above the rest.

7. One of the writers (Allen) has in numerous researches on sensory activities generally regarded the central organs as unchanging in sensitivity, and the receptor organs as mechanisms which fluctuate in excitability when stimulated. One result of the present experiments is the demonstration that a central sensory area oscillates in sensitivity when the receptors of other sense organs are stimulated, and also when the receptors to which it is directly attached are stimulated. To ascribe those phenomena of vision, in which fluctuation or alteration of intensity of response is concerned, to the retinal receptors exclusively is now clearly seen to be erroneous. Many such phenomena must originate in fluctuations of responsiveness of the central organs. The modification of the hues of contiguous fields of color by their mutual action upon each other, known as simultaneous contrast, is one group of phenomena which would now appear to arise in the central centres of vision and not in the visual receptors in the retina. One cannot, however, arbitrarily assign either to the

peripheral or to the central organs the phenomena of oscillation. All parts of the sensory apparatus, peripheral, intermediary, and central, have important functions to perform in the excitation of sensations. The complete sensory apparatus from periphery to centre must be regarded essentially as a unit; and stimulation, response, and radiating influence upon other organs are to be viewed as but the several aspects of its complete and complex function.

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