II.—SUBJECTIVE COLOURS AND THE AFTER-IMAGE: THEIR SIGNIFICANCE FOR THE THEORY OF ATTENTION.

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SOME time ago, while studying what is called the "flight of colours" in after-images produced by white light, it occurred to the writer that it would be interesting to observe the effect on this colour series of an effort to alter the colours subjectively. The following paper is in part a description of the results obtained in a series of experiments bearing on this problem, and performed during the winter and spring of 1898. By "subjective colour sensation," or "subjective alteration of colour," is meant the effect of an attempt to call up in the retinal field of the closed eye, or with open eyes in a dark room, the sensation of a given colour. Prof. Külpe notes in his *Outlines*, §§ 28, 2, and 74, 3, that it is possible in a dark room to call up at will patches of various colours, and that these central excitations sometimes approach the intensity of peripheral excitations. The problem here investigated relates simply to the influence of centrally excited sensations produced by such efforts upon the ordinary "ringing-off" of after-images.

It may be noticed at the outset that these experiments failed to show one hoped for result, which may perhaps yield itself to further investigation. During some of the earlier and less carefully controlled experiments, the effect of an effort to tinge the after-image with a certain colour seemed to be an intensification of the complementary colour; e.g., a stage which in the preceding experiment had been whitish or indefinite in colour flashed out into vivid green when the subject attempted to turn it red. The obvious suggestion was that this was a contrast-effect, and contrast of a new order, so far as the writer was aware, where the inducing colour was of purely central origin. The supposition was rendered more plausible by the recollection of an experience that occurred some years ago. While spending a few days in an unfamiliar house I noticed from time to

time a bit of vivid red drapery hanging on the wall of a room. On one occasion, entering the room hastily and glancing toward the red drapery, I saw a distinct patch of green on the white wall, and it was a second or two before I realised that the red cloth had been removed, and that what was actually seen was the white wall itself. I can think of no other explanation for this phenomenon, which was as unmistakable as it was unexpected, than the hypothesis that the green patch was a contrast colour, induced by the *expected*, centrally excited, or subjective red. Nor is this hypothesis really weakened by my failure to find analogous results in the experiments described below. In the case of a phenomenon which can occur only when favoured by very complex conditions, one well-marked positive instance should outweigh a number of failures. As a matter of fact, the apparent contrast-effect in these experiments turned out later to be due in all probability to alterations in the brightness of the stimulating light.

The image used as a basis for the following experiments was that produced in the retinal field of the closed eyes by prolonged white-light stimulation. The conditions were carefully regulated in accordance with those laid down by Helmholtz in the *Physiologische Optik*. The subjects sat in a room lighted by the upper half of a window whose lower half was screened. The eyes were fixed upon one point of the window-frame for twenty seconds, and were then closed and covered. Nothing but sky could be seen through the window, and careful note was always taken of the degree of illumination. The precaution was, of course, observed to free the eyes entirely between experiments from all traces of the previous image. The subjects experimented on were the writer (*W.*) and three students of psychology (*M.*, *O.* and *D.*). Of these only *W.* had general practice in psychological experiments. Fortunately, however, a reliable test could be had both of the degree of special practice attained by the subjects in the course of the research and of the influence of external sources of error. This test lay in the uniformity of the colour changes observed in the ordinary unmodified image. A wholly unpractised observer watching the course of an after-image for the first time reports chaotic results, and no two such observers agree as to the alterations in colour which occur. No results were taken account of from any subject until she was sufficiently practised to find the colour changes approximately uniform or affected only by such fluctuations as could be accounted for from external causes.

The first point to be determined was the sequence of colours to be expected from the ordinary image under these conditions. This was ascertained by a series of forty experiments made by *W.* at the outset of the research; the other subjects being then practised as stated above, till their accounts of the course of the image were consistent. Throughout the research at the beginning of each hour's work, and at intervals during its progress, two or three observations were taken of the ordinary unmodified image. The results obtained were almost perfectly uniform. After the momentary positive same-coloured image which appeared immediately on closing the eyes, there was an interval of five or six seconds, when a positive image came again. This image was at first rather fluctuating in colour, patches of red and green sometimes appearing on it, but in a second or two the panes of the window filled out with sky blue, the window bars remaining dark. This blue stage then passed into a stage of vivid green, the image sometimes but not always disappearing between the two stages. The green image usually disappeared and reappeared five or six times, growing paler, almost whitish, in colour towards the end. This neutralising of the green tint seemed to be due to the gradual emergence of the complementary colour, for the image next assumed a deep red tone, while the black bars became luminous and slightly greenish, the light appearing first as a crack through the length of each dark bar. Here, of course, was the transition from the positive to the negative image. The red stage, after undergoing several fluctuations, gave place to a deep blue image with yellowish bright lines, which lasted longer than any of the preceding, growing gradually darker until it became indistinguishable. By one of the subjects (*O.*) this final image was described as dark green, or sometimes as bluish green. No other important exceptions to this sequence were noticed with practised subjects, and it corresponds to that observed by Helmholtz under similar conditions. Experiments made with ten and fifteen seconds' exposure also confirm Helmholtz' statement, that after a certain limit has been passed the duration of the stimulus does not affect the course of the image. Variations in the intensity of the stimulating light did, however, influence the colour changes of the image. The sequence just described occurred when the sky was unclouded, or when it was covered with thin clouds and presented a uniformly white surface. When the illumination was much diminished, the sky uniformly and heavily clouded, the blue and green positive images were lacking.

The first image in the regular series was reddish white with dark lines. The colour gradually deepened, and the red negative image appeared, followed after several fluctuations by a dark blue negative image, very bright and distinct. The blue and green positive stages were regularly omitted when the sky was darkened ; and the effect noted above, the brightened green which appeared several times when the subject tried to turn the image red, was very likely due to a brightening of the sky, as it was not observed in the later experiments, which were never made when the sky was in a condition to render the illumination variable in any marked degree.

When the subjects were sufficiently practised to be familiar with the ordinary course of the image and to find it regular, they were told before the experiment that they must by an effort of will turn the image red all the way through its course ; that they must force back the other colour stages, or make them as brief as possible by fixing their attention on the idea of red. It was suggested that this could be brought about best by thinking hard of something red, at the same time trying to call up the colour in the retinal field ; by fancying, for instance, that the window-panes were pools of blood. Corresponding suggestions of green and blue were made in other experiments ; the subjects being told to think of green grass or blue sky. It soon became apparent that the carrying out of these suggestions was much easier for one of the subjects (*D.*) than for the other three. While *M.*, *W.* and *O.* have moderate visualising powers, *D.* is a good instance of the predominantly visual type, and was selected as a subject for that reason. In the case of the former, intense effort was needed to keep the attention fixed on the colour to be produced. This effort was manifest in a rigid position of the body, in frowning and biting the lips, and in a general expenditure of muscular energy, which became very fatiguing. The subjects often tried to reinforce the visual excitation by associated sound and muscular excitations, repeating internally the words 'red' or 'green' while trying to call up the colours. The strain of all this was found by the writer to be so great that the conditions of the experiment were altered, and instead of being required to visualise one colour throughout the whole course of the image, the subjects were asked in one set of experiments to turn the image red, blue, or green during the first half of its course, that is, up to the point where it passed from the positive to the negative stage ; and in another set to wait until the image was entering upon the

negative stage, and then to try the subjective colour. In the case of the subject *D.* no such division of the experiments seemed necessary; much less effort was required to visualise the desired colour, simply thinking of some red, green or blue object being apparently sufficient.

The first set of results to be discussed are those obtained from the subjects *M.*, *W.* and *O.* Experiments where the effect of subjective red on the first half of the image was studied will be referred to as the *R. I.* experiments; those with subjective green in the first half as the *G. I.* experiments; those with subjective blue as the *B. I.*; while experiments with subjective red, green and blue in the second half will be designated as *R. II.*, *G. II.* and *B. II.* respectively.

The effect of subjective red in the *R. I.* experiments was manifested in three ways: (1) The blue positive image was observed to be strongly tinged with red. This effect was never visible on the green positive image, which resisted all efforts to turn it red. However (2), the dark lines on the green positive image were often made to assume a distinctly reddish tone; and (3) the blue and green stages were not infrequently much shorter than in the unmodified image, the effort to turn them red having apparently the effect of bringing on the red stage sooner than usual.

In the *G. I.* experiments the subjects were asked to make the image green at its first appearance, shortening or obliterating the blue stage; to hold the green as long as possible, and when the red stage appeared to force it back into green. It was found (1) that the blue image was tinged with green; (2) that its duration was distinctly shortened; (3) that the green image was noticeably brighter, and lasted longer than usual; and (4) that in some cases the green colour could be brought back after the image had turned red. The subject *O.*, to whom the final negative image looked dark green instead of dark blue, found that the effect of trying to bring back the green colour after the image had entered the red stage was to "hurry it on" into the final green negative image.

The chief results of the *B. I.* experiment were (1) that the blue positive stage was brighter and of longer duration than in the unmodified image; and (2) that blue patches appeared on the green image. *W.* also noticed during many of these experiments flashes and patches of blue light in the retinal field near the image.

In the *R. II.* experiments the effort was made to hold the red image as long as possible, and when the dark blue or

dark green colour began to appear to force it back into red. It was found (1) that the red image was brighter and lasted much longer than usual; (2) that the red colour would frequently be brought back even after the image had turned completely blue or green; and (3), by the subject *O.*, that when the image had become very dark and indistinct, and was on the point of disappearing, it could be made to look reddish.

The subjects were told in the *B. II.* experiments to shorten the red image and to bring on the dark blue negative stage as soon as possible. This result was obtained, and the blue negative image appeared brighter and lasted longer than usual. The subject *O.* found that under these conditions the final stage of the image was quite distinctly blue instead of green.

The attempt in the *G. II.* experiments was to shorten the red stage, and to turn the final blue negative image green, if possible. This latter result was of course most strongly marked in the case of the subject *O.*, who found the final image distinctly green. The dark blue negative image was, however, noticeably tinged with green for the other two observers. Another result was that the lines on both red and blue negative images appeared bright green in colour.

These results were not uniformly distributed throughout the experiments made in each class. Sometimes only one effect, *e.g.*, the brightening of the blue or green image, would be noticed. Sometimes several effects would appear in the same experiment. In from one to two per cent. of the experiments the effort to visualise produced no result at all. The high degree of strain put upon the attention subjected the results to variations arising from causes too slight and obscure to be traced or calculated, and a table showing the relative frequency of the effect described above reveals an irregular distribution from which no general principles can be deduced. The results themselves seem to fall, broadly speaking, into two classes, which, however, are not separated by any sharply defined line.

The first class comprises cases where the effect of visualising a certain colour was simply to intensify the traces of that colour already present in the retinal field. Central excitation of a given colour meant in these cases merely "calling attention" to that colour whenever it was actually present. In other words, it was an instance of what Prof. James calls "ideational preparation" for attention; the facilitation of attention to a given conscious contents by expectation. The results which fall into this class are: (1) the brightening

of a coloured image by central excitation of the same colour ; (2) the appearance of patches of the visualised colour on images of other colours. The writer found that in her own case these patches of red on the blue image or of blue on the green were not infrequently present when there was no attempt to visualise red or blue ; and interpreting the reports of the other subjects from her own experience, concludes that they were merely not noticed except when the subject had their colour specially in mind.

To the second class of results belong those cases (1) where the image of the visualised colour was brought on sooner than usual, the preceding stage being very considerably shortened ; and (2) where it was held longer than usual, the succeeding stage being as it were thrust back when it began to appear. Here we have apparently not merely an intensification of sensations already peripherally excited, but either the production by central excitation of a sensation equal in intensity to the peripherally excited image, or the checking of a peripheral by a central excitation. Really, however, this second class of results is merely an exaggerated instance of the same principle manifested in the first class. Here, too, in all probability, a peripheral excitation is strengthened by a central excitation, only the former is so faint that the resulting sensation seems to have been produced wholly by central excitation. There is always a tendency for the colour of the after-image to fluctuate between stages. Some time before the green stage, for instance, actually passes into the red stage, the red process assumes more or less prominence, and after the red stage has appeared there are still traces of the green process surviving. If the subject is visualising red, the nascent red excitation will be strengthened and made predominant ; if green, the fading traces of green will be held and intensified against the in-coming red.

In the case of the subject *D.* the effect of centrally excited colours on the course of the after-image was very striking. It amounted in many experiments to an entire transformation of the colour series. The subject's own report of one or two experiments will give the best idea of the extent of this effect. The ordinary sequence of colours in the "ringing-off" was for *D.* perfectly regular ; blue positive, green positive, red negative, dark blue negative. When in the next experiment, after an interval sufficient to remove all traces of the preceding image from the retinal field, the subject was asked to visualise red, the course of the colour changes was described as follows : First a red image with

dark lines lasting some time and growing lighter, interrupted once by a momentary green image. The lines then became bright, and the red negative image remained until the end of the series, traces of blue appearing from time to time. After the usual interval, the subject was asked to turn the image green in the next experiment, and the following colour sequence was obtained: A light green image with dark lines, the lines gradually becoming reddish; then a red image with green lines, the lines spreading till the whole image was dark green, which it remained until its entire disappearance. Finally, where blue was visualised, the sequence of colours was: purple positive, light blue positive, light blue positive with greenish lines, very short red negative, vivid blue negative with yellow lines.

Such results as these show that for a person with unusually vivid powers of visual imagination, central excitation of visual centres, whose peripheral excitation by white light is so far weakened that the corresponding colour sensations have quite disappeared from the after-image, may reinforce their activity to such an extent as to make their sensations predominate in the image. We have here an extreme case of the effect of central reinforcement on weak peripheral excitation; an effect which appears to a less marked degree in the results from the other subjects.

The most obvious theoretical consideration suggested by these phenomena is one which hardly needs to be dwelt on, since it has been recognised for so long and is supported by so many other lines of evidence. I mean the fact that perception and idea differ ultimately only in the manner of their production. The after-image, while of peripheral origin, stands in point of intensity midway between the two. Here, where the intensity of the peripheral process is reduced to a minimum, the resulting conscious state is seen to be practically identical in character with that produced by central excitation. But the chief interest of these experiments is their bearing on the theory of attention. The writer can state from her own introspection that for the three subjects of moderate visualising powers the effort to call up subjectively a certain colour meant simply an unusually intense effort to attend to that colour. That is, the central excitation of the visual centre was of the same order as that which occurs when one prepares to attend to certain conscious contents, *e.g.*, a certain overtone in a clang. Now if these experiments show anything, they show that the function of attention is positive as well as negative, intensifying as well as inhibiting; and further that

its positive effects are due to the fact that, whenever we 'voluntarily' attend to any peripherally excited conscious contents, its peripheral excitation is reinforced by a central excitation, and its intensity is thereby actually increased. This effect of increased intensity would naturally be especially well-marked and unmistakable in the case of after-images, where the peripheral process is of but slight intensity. Nothing but an actual reinforcement by central excitation can account for the cutting short or lengthening at will of the colour stages in the after-image.

The evidence which these experiments afford of the function of central excitations in attention suggests a criticism of the reason for assuming the existence of a special 'attention centre' somewhere in the frontal lobes. Every function which the attention or apperception centre is supposed to perform can be explained on the hypothesis that the organ of attention is the cortex as a whole; or more definitely, the sum total of those brain centres which are connected functionally according to the laws of association and habit with the centre whose accompanying conscious process is the object attended to. Attention means central reinforcement of an excitation which may be in the first instance either central or peripheral in origin. And this central reinforcement comes not from a single supreme centre, but from associated centres of the same order as that in which the original excitation takes place. The influx of nervous energy which occurs in such a process of course involves increased intensity on the part of the resulting conscious state. It also involves diminished intensity in the rest of the field of consciousness. For the cortex as a whole represents a certain limited amount of nervous energy. When the currents of central excitation are determined to a given brain centre or group of centres, the intensity of nervous processes elsewhere is necessarily diminished, precisely as the electric lights in a trolley car grow dimmer when the car starts. Hence comes the phenomenon known as abstraction, which surely needs no such hypothesis as that of an inhibitory influence exerted by a special centre.

Although attention is thus seen to involve increased intensity on the part of the mental state attended to, it does not follow that the more intense a conscious state is, the greater the degree of attention to it. The increase in intensity must be of central, of associative origin. Otherwise an idea could never be attended to in the waking life, unless it assumed the intensity of an hallucination. It is not the

fact that a monotonous sound suddenly becomes louder that constitutes the fact of its being attended to; it is the sudden stirring up of associated ideas of its cause and significance, the 'what's that?'—not the increase of intensity due to the external stimulus, but that due to the influx of excitation from associated brain centres. Such, at any rate, is the view of attention suggested, rather than proved, by the experiments described above. The writer hopes that as an hypothesis it is at least worth considering, if only to be rejected upon other evidence.