ADAPTATION WITH NEGATIVE AFTER-EFFECT

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Psychologists have in the past directed a great deal of effort toward classifying the sensory categories of our world—distinguishing, delimiting, and introspectively analyzing its qualities; but they have spent very little time in noting or studying the functional similarities which cut across these categories. That red, sour and warm are distinct experiences, based on different processes, has been emphasized to the neglect of the fact that they all manifest adaptation and other phenomena in common. Holt and Yerkes (**12**) prepared in 1903 a laboratory manual of experiments on sensation in which the emphasis was laid upon phenomena common to the various modalities and qualities—latency, after-image, adaptation, contrast, fusion, inhibition, and others—and in general upon the similarities between the senses rather than the differences. But this lead has not been followed in experiments to any significant extent.

The fact that the simpler sensory processes often behave in a strikingly analogous way to reflex processes with regard to such phenomena as threshold, latency, summation, inhibition and after-discharge should indicate that it would be profitable to look for common principles underlying the various senses. It is hardly probable that every sense is, so to speak, a law unto itself. The similarities which cut across sense departments point to the possibility of new categories and concepts in sensory psychology which might be of great theoretical value.

It is the purpose of this paper to describe in general terms one principle which can be found to apply to a variety of sensory dimensions and to exemplify it wherever possible. The principle is that of *adaptation with negative after-effect.* This lengthy phrase will generally be used in preference to

successive contrast because the latter term may imply an after-effect without correlative adaptation. It is clear, of course, that there are forms of sensory adaptation not accompanied by any negative effect, but on both logical and evidential grounds it seems certain that there cannot be a negative after-effect without adaptation. It is also clear that there are after-effects of sensory stimulation, such as the positive after-image and 'after-discharge,' which are not negative or opposite and hence are not included in the principle.

A generalized statement of adaptation with negative after-effect is as follows: *If a sensory process which has an opposite is made to persist by a constant application of its appropriate stimulus-conditions, the quality will diminish in the direction of becoming neutral, and therewith the quality evoked by any stimulus for the dimension in question will be shifted temporarily toward the opposite or complementary quality.* To take an example from the most obvious source, if a blue stimulation is prolonged, the hue loses saturation or approaches gray. Any other color stimulus which is now applied will be found to produce a hue which is shifted toward the yellow. A saturated blue is less saturated, a weak blue is gray, a gray is yellow, and a yellow is more yellow.

This formulation employs several notions which need examination: *dimension*, *opposite*, *neutral*, *appropriate stimulus* and *shift*. It is not a new idea that sensory qualities fall into dimensions, continua, or series (4). In fact, the psychophysical method by which nearly all research on sensory processes is accomplished—the judgment of 'more' or 'less'—presupposes that a dimension exists. Discrimination implies a serialization of the qualities discriminated. What needs to be pointed out here is that there are a number of types of such dimensions. A sensory continuum such as pressure, or size, or olfactory intensity, or distance, or duration is not the same kind of continuum as one like temperature (warm-cold) or brightness (white-black) or kinæsthetic right and left, or simple linear shape (convex-concave). The former is what might be called a unilateral or *intensive* dimension, the latter a bilateral or *oppositional* one. In the first type the qualita-

tive series runs from zero, *i.e.*, an absolute threshold, up to a maximum. The ends of the series are conventionally indicated by such terms as low and high, weak and strong, or little and great. The quality is the same throughout the series. In the second type, however, the series runs from a maximum of one quality through a neutral quality to a maximum of an opposite quality.

An *opposition series* of this sort has interesting properties. First, the two qualities intensify as they deviate from the neutral or, conversely, diminish as they approach the neutral. Second, the qualities may be said to cancel each other in a real, physical or physiological, sense. Third, they are complementary opposites; each presupposes the other. Hence an opposition series is not merely two intensive series with a common zero-point. Fourth, the neutral quality is unique. It is neither the one quality nor the other, but the point of departure for both of them. It is usually precise—discriminated with great acuteness—as is gray between blue and yellow or the neutral point between warm and cold. Fifth, the two maximum qualities constituting the limits of the series may or may not be precise and specific. These maxima may be set by physiological factors of sensitivity (*e.g.*, the upper threshold for speed of visual movement) or by a transition to a different sensory dimension (*e.g.*, cold into pain). Sixth, the neutral quality is the norm or standard of the series, with reference to which absolute, as distinct from relative, judgment is possible. Significantly it also corresponds to the average or the most frequent stimulus condition. In some cases the limits of the series may serve also as standards of reference when they are sufficiently specific. In the brightness-series, for example, black and white are more precise norms than middle gray.

The opposition of the two qualities deserves a further explanation. It probably consists in the fact that the same object can not be made to carry both qualities at the same time. The same surface can not be both blue and yellow, or warm and cold; the same line can not be both concave and convex; the same object can not appear to move both up and

down or to be felt both to the right and to the left. These qualities and their conditions are incompatible. Whether the opposition is ultimately physiological or ultimately physical is not so important for our purposes as is the fact that if one attempts the operations necessary to produce in a subject both qualities simultaneously, one is thwarted. The one operation cancels or negates the other and the resulting sensory process corresponds to the neutral or normal quality.[1]

Qualities may fall into other types of dimension than the two described.[2] Notably there is the type which consists of the transition between two different but not opposite standard qualities. Examples would be: red to yellow, fragrant to ethereal, the transition from one shape to another, or the series of varying orientations from a square to a diamond. The three types which have been distinguished are the *intensive* dimension, the *oppositive* dimension, and the *transitive* dimension. Only the second of these is of immediate interest to this discussion since our thesis will be that *whenever experiential qualities fall into an opposition-series, then adaptation with negative after-effect may be expected to occur.*

The quality evoked by any stimulus of the dimension in question will be shifted temporarily toward the opposite quality. This statement means that not only the quality normally evoked by the persistent stimulus but also any other quality in the series is shifted from its usual stimulus-base. There has been produced an alteration in the correspondance between stimulus and quality throughout the series. In other words, we must take into account not only the sensory dimension but its correlative stimulus-series. A prolonged stimulation, if it is not at the neutral center, will result in a change of the stimulus-response correspondence throughout such that the discrepancy between the sensory quality and the norm is reduced or in some cases even destroyed.

The fact that the prolonged application of a single stimulus-value may modify the sensory equivalences of all other

[1] An interesting treatment of opposition from a logical and philological point of view is given by Ogden (16). It is clear however that the problem of the nature of opposites is exceedingly confused.

[2] Auditory pitch perhaps constitutes a type of its own and can not be classified.

stimulus-values in its series is important. There is implied still another property of the opposition-series as a type of sensory dimension, namely, that it is in some sense a unit. The qualities which make it up are wholly interdependent; when one quality is changed, all the potential qualities are changed with it. This fact points to a much more general hypothesis with which we shall deal later, namely, that if every sense-quality falls on a dimension of some type, and if every dimension is a functional unit, as is the opposition-series, then it is possible to speak of *a* sensation and *a* stimulus only so long as one means a point on a scale. Only so long as one bears in mind that correspondences between such sensory and stimulus points are individual cases of a coherent system —a serial correspondence which may be changed as a whole— can the terms be accurately employed. This is a point which has been emphasized by Koffka (**14**). A sensory dimension is functionally 'all of a piece'; the series is a discriminatory unit.

The hypothesis in general is that adaptation and negative after-effect are to be conceived as a process of adjustment and readjustment of the physical-phenomenal correspondence of a certain type of sensory dimension, under the influence of a tendency for sensory activity to become normal, standard or neutral.[3] The formulation described can be shown to be applicable to a number of types of sense experience, and the rest of the paper will be devoted to these applications.

Color—"Chromatic adaptation," as Troland has said (**22**, p. 181), "operates so as to shift the hue which is evoked by any stimulus in the direction of the complementary of the adapting stimulus." The negative after-effect of color, being closely confined to the stimulated area of the subjective field and being subject to the tendency of all visual processes to be projected, has been called an *image* and there is a temptation to think of it as thing-like—as akin to a stimulus or at least to a retinal process. But that it is equally well conceived of

[3]The terms *normal*, *standard* and *neutral* will all be used to characterize the mid-quality of a sensory opposition series, since these different shades of meaning can not be compressed into one term.

as a temporary shift in the stimulus-quality correlation, a little reflection will show.

The examples already discussed have shown how our formula may be applied. Among the chromatic qualities, any number of opposition-series may be plotted between complementary hues, the familiar ones being red to blue-green, yellow to blue, and green to purple. All these dimensions must make up a single system, since the interesting fact is that chromatic adaptation along one dimension produces a change in all color-equations, not merely the dimension concerned. It is as if a prolonged hue became shifted toward the neutral center of the color-circle carrying with it all other points of the circle including non-complementary ones.[4]

Brightness—The occurrence of adaptation with negative after-effect in the case of brightness is less obvious than it is for the chromatic qualities. The dimension is determined in a more complex manner, since both photopic and scotopic vision enter into the picture and since brightness may refer either to whiteness of a surface or the illumination of the general field. Furthermore, the physical intensity of the stimulus corresponding to the neutral quality may vary widely. Nevertheless, events seem to be essentially the same; a positive brightness-value of the stimulus decreases in the direction of becoming neutral and accordingly the qualities shift all along the line. What was formerly dark becomes still darker, the former neutral is now dark, etc. 'Sensitivity' has been lowered for all stimulus-intensities. The converse holds if a negative stimulus is applied, *i.e.*, a stimulus of lower physical intensity than that of the neutral level. In this case the 'sensitivity' of the visual mechanism has been heightened and all brightness values shift upward on the scale (**22**, p. 93 f.). This formula seems to apply both in photopic and in scotopic vision. It fits not only the facts of the familiar laboratory demonstration using black, gray, and white papers, but also the results of the more precise experiments using

[4] A lowering of the brightness of the adapting hue, however, may apparently upset the simple rule of a shift in the complementary direction. The 'dimming effect' reported by Troland (**20**) yields after-effects of chromatic adaptation into which other factors enter.

luminous stimuli. It also corresponds to the facts of 'light' and 'dark' adaptation, where the after-effect obviously does not take the form of an after-image. A feature of this latter phenomenon is, in our terms, that the adaptation may be complete, which means that the persisting quality may not only shift toward, but may become, the neutral or normal quality. The general level of brightness-adaptation may shift up or down the scale with great freedom. A *localized* adaptation process, on the other hand, is commonly both chromatically and achromatically incomplete; according to Troland (21), the hue never reaches a neutral gray except with a low saturation to begin with.

It is true that the black-white series does not have a sharply defined neutral mid-point which furnishes a standard for the dimension, although, since Hering, middle gray has often been urged as unique, but it is still true that the brightness series is more nearly an opposition-series than it is an intensive series. For one thing there is apparently no possibility of a visual 'silence' or lack of sensation. Psychologically there is no visual zero with nothing below it, black or darkness being an actual quality. The conventional treatment of brightness adaptation in terms of the variable sensitivity of the visual mechanism to *light* obscures the similarity of the process to what is here called adaptation with negative after-effect, but it may be urged that the difficulty is mainly terminological.[5]

Temperature: warmth and cold—The characteristics of a sensory opposition-series are very clearly exemplified in this dimension. The opposition of the warm and cold qualities is clear-cut despite dubious theories of their fusion to yield heat. The neutral quality is definite, it is quite obviously a norm, and it constitutes the psychological point of reference for the series. The limits of the series are furnished by the

[5] It has been maintained that black and white are not antagonistic qualities like complementary hues because when mixed on a color-wheel they do not inhibit one another but fuse instead. Whether gray is considered a product of fusion or of inhibition is perhaps a matter of choice. It must be admitted, however, that the brightness-scale is a less perfect example of the opposition series than other sensory dimensions.

transition to heat and pain qualities at the upper end and pain at the lower end (**15**). Consequently, it is to be expected that adaptation and the opposite effect of this adaptation upon subsequent stimuli would be prominently exhibited, and such is the case. If a stimulus at about 33° C. feels neutral, as it normally does, and the skin is then adapted to warmth at 36° C., 33° feels cold and all stimuli over a wide range should feel colder than they would have felt under the earlier conditions. How far up and down the scale the shift remains uniform is not known but this should be susceptible to an experimental test. The norm of the temperature-series (the psychological zero) is so adaptable that it may be raised as high as 39° C., whereupon 37° C. feels cold, or it may fall as low as 11° C., whereupon 12° C. feels warm (**1**). Within this range any process of adaptation is complete; the discrepancy between the prolonged quality and the norm wholly disappears; the temperature perception becomes normal or neutral. Some time may be required for adaptation to reach the level where, for example, a finger immersed in cold water yields no temperature experience whatever, but the fact that it does so seems to be well established. With respect to this flexibility of the stimulus-quality correspondence, the temperature sensitivity of the skin seems to be similar to the general brightness sensitivity of the retina. Furthermore, as in the case of both color and brightness sensitivity, when the adapting stimulus is localized rather than general the effect is confined to the stimulated area of the sensitive field. Localized temperature adaptation may, however, be complete where localized visual adaptation under most circumstances is not.

The qualities of a simple line—The sensory qualities which have so far been discussed are orthodox ones which no one would dispute. The proposition that a simple line is a sensory quality—or character, or modality—is less orthodox. William James argued convincingly in 1890 that a line was a sensation pure and simple (**13**, p. 152), but the accepted list of sensory categories has never included it, even though it possesses all the necessary 'attributes.' Recently, as a part

of the reaction against the older structuralistic categories, contour and the figure-ground phenomenon have been accepted as basic visual processes. The visual *line*, however, has been left out of account by both schools of thought. It is logical to suppose that line, the accompaniment of any areal difference of color within the visual field, is an even more elementary process than is contour or figure. Things are seen in the first analysis because they are delimited in vision, and this delimitation involves the formation of a line. The fact that a line may have the function of enclosing or serving as a contour with an 'inside' and an 'outside,' yielding thereby a figure on a ground, may be considered a separate step. A line is a simple, unanalyzable and fundamental mode of visual experience.

Against the above assertions there is set, of course, the historically conditioned tendency to distinguish sharply between sensation and perception, between secondary and primary or subjective and objective qualities. A line, it would be contended, is no sensation; it is a thing with objective existence. Since a sensation refers to a receptive process in the organism and a perception refers to an object, linearity must be perceptual. For the present it will only be suggested that this historical dichotomy is a false one. *Sensory* and *perceptual* are here assumed to be useful relative terms which can not be distinguished by any absolute criterion.

A line, or any selected portion of a line, may be said to have two qualitative dimensions which define it psychologically in the same way that hue, brightness and saturation define a color. They are its shape and its direction. For lines in the frontal plane, shape means the convex, straight, or concave quality of the line or the segment; direction means the standard (vertical or horizontal), or inclined quality. The mathematical equivalents of these sensory qualities—the direction and the shape of a line—are expressed as the first and second derivatives at any point, that is to say, as the slope and as the way in which the slope is changing.

Both these qualities fall into dimensions which fulfill the requirements of an opposition series. Both manifest adapta-

tion with negative after-effect in a manner which points to their kinship with sensory processes.

Linear shape: convex-straight-concave—A line is usually straight, but this standard quality is only the neutral one between two opposite qualities which a line may bear. Taken as a whole or in any part which one wishes to consider, the line may be curved or bent in either of two directions each of which is complementary to the other. These qualities of non-rectilinearity may vary in intensity. Like opposite saturations of color, they intensify as they deviate from the norm. A sharp bend may be regarded as an intense non-rectilinearity confined to a small segment of the line, a gradual curve as a less intense non-rectilinearity spread out over a larger segment. Both the bend and the curve are varieties of linear shape. For lack of a better term, 'curvature' will be employed generically. The various degrees of curvature, then, together with the norm, form an opposition series. The limits of this particular series are vague and unspecific. It is impossible to say what the maximum curvature of a line can be, since a high degree of curvature on a sufficiently extended line begins to be a contour instead of a line.

Adaptation with negative after-effect for curvature of a line has been reported by the writer previously (**8**). If a subject is required either to fixate or merely to look at a curved line, the quality of curvature decreases in the course of time and *in that particular region of the subjective visual field* a straight line appears curved the other way. The same is true of a bent line if the subject's gaze is confined to the section of the line where the bend appears. The phenomenon is quite independent of the direction or orientation of the line as a whole. If curvature is measured in units of displacement at the middle of a line of constant length, then the amount of decrease in curvature during adaptation is equal to the apparent opposite curvature of a straight line. There has occurred a uniform shift in the curvature-quality of any line seen in the adapted area. In other words, when a retinal curved line is represented phenomenally by a less curved line, then a slightly curved line is correlated phenomenally with a

straight line, and a straight line with an oppositely curved line. A displacement of several millimeters in a 30 cm. line may take place with a five minute period of adaptation and the after-effect will persist for several minutes thereafter. The phenomenon has been verified by Bales and Follansbee (2).

This effect can not be classified as an illusion of judgment (although all of the effects we are discussing are fundamentally analogous to judgment-contrast) if for no other reason than because, like the after-image, it is localized. Curvature-adaptation bears the earmarks of what has traditionally been called a sensory process. Like color-, brightness- and temperature-adaptation it can be represented as a shift of the physical-phenomenal correspondence of such a sort as to make the present sensory quality more nearly normal. This shift, however, is very slight in amount as compared to the dimensions so far considered; the physical-phenomenal correspondence is relatively rigid in contrast to the flexible correspondence found in temperature-sensitivity. The concept of relative rigidity or flexibility of this dimensional correspondence might serve as a partial substitute for the ancient concept of primary and secondary qualities.

Tactual-kinæsthetic shape of an edge—A line is 'perceptual' rather than 'sensory,' it might be argued, because it is present to more than one sense. In the form of an *edge* it may not only be seen but touched and felt. It is true of course that objects are delimited tactually as well as visually and that surfaces and lines are haptic as well as visual data. But a tactual edge is subject to adaptation with negative after-effect no less than is a visual line. As the writer has demonstrated (8, p. 17), if a concave (or convex) edge is actively felt by a blindfolded subject for a few minutes, the curvature decreases and a straight edge then feels convex (or concave). The shift in curvature represents a displacement of over 1 cm. in a 30 cm. line. An edge which is curved in the same direction feels straight and by this determination the effect can be measured.

Linear direction: standard and tilted—The directional quality of a line or a segment of a line may abstractly be treated independently of its shape, although the two are intimately related. Within the frontal plane, direction is discriminated with reference to the norms of horizontal and vertical. These standard directions are set between opposite qualities of what can be called 'tilt.' Psychologically a tilt with reference to the vertical may be either to the right or to the left. Equally, the vertical is simply that neutral direction which is tilted neither to right nor to left. In this case, it is not difficult to understand what is meant by saying that the opposition-series is a discriminatory unit or that the qualities are interdependent. The limits or ends of the opposition-series whose norm is the vertical interlock with those of the series whose norm is the horizontal. Consequently at 45° clockwise from the vertical the experienced tilt is equivocal; it may be a tilt to the right of the vertical or to the left of the horizontal. The same, conversely, is true of the other 45° position.

Psychologically, then, the direction of a seen line is an immediately sensed quality which may vary within two interlocking dimensions of the type in which we are interested. These opposition series have their *centers* at the horizontal and vertical—not their limits. The dimension *beginning* with the vertical and *ending* with the horizontal would constitute what has been called a transition series.

This description is not entirely *a priori* since it derives from an experimental setting (**9**, **10**, **17**). It can be demonstrated that a process analogous to adaptation with negative after-effect occurs in this type of perception also (**9**, **10**). In the course of a continued fixation or inspection of a tilted line the inclination appears to decrease slightly and a line objectively vertical (or horizontal) thereupon looks tilted in the opposite direction. After a 5 min. period of adaptation the shift of linear direction may be 2° or 3°. A 10° tilt looks like 8°, 2° looks vertical, and the vertical looks like − 2°. The effect does not apply to the visual field as a whole but is roughly limited to the region previously occupied by the

stimulus-line. When one axis has been altered in this manner the other axis is found to be altered in the same way, although not to the same degree. In other words, the rotatory shift in the apparent direction of a stimulus-line *tends* to be the same throughout the whole gamut of visual directions in the affected area. In accordance with our general formula, we may suppose that a prolonged perception of tilt adapts in the direction of its vertical norm if it is tilted from the vertical (or its horizontal norm if it is tilted from the horizontal), carrying with it the qualities of its own dimension and even to some degree the qualities of the other dimension. A tilt of 45°, on this theory, should not show any adaptation toward either norm, and actually it does not (**9**, **10**).

Tactual-kinæsthetic direction—It is not difficult to show that the direction of a line in the frontal plane, like its quality of shape, behaves in the same way when actively felt as when seen. A yardstick mounted on a bearing at its midpoint and supported in front of a blindfolded subject so that he can put one hand on either end and adjust its direction to the horizontal or vertical position will serve to demonstrate the phenomenon. Under normal conditions the stick can be set at horizontal with some accuracy. But after a few minutes of actively feeling the stick in a position tilted down to the right from the horizontal, the abnormality diminishes, the actual horizontal then feels tilted down to the left, and an actual tilt of several degrees to the right feels horizontal.

Visual Movement—Since the investigations of the phi-phenomenon, it is no longer a novelty to suggest that movement is akin to a sensory quality, or at least to suggest that it is not a composite of other sensations. But here, again, a sharp distinction between sensory and perceptual processes leads to unprofitable arguments. Motion is surely a dimension of visual experience. And, what is more important to us, some motions are the opposites of others. Their opposition is of a very simple sort—opposition of direction. In fact any experience of motion can be given its place in an opposition series which varies from the highest perceptible speed of movement in one direction through immobility to the highest

possible intensity in the opposite direction. There are of course as many of these oppositional dimensions as there are directions in visual space. It may at first appear a little forced to claim that immobility is itself a visual quality of objects—the neutral between opposite qualities of movement —but this normal immobility of things is definable only as absence of motion, and is discriminable only with reference to these qualities, and is therefore as truly a quality of experience as is motion.

According to the formula which we have proposed, a prolonged experience of movement in any part of the visual field should decrease in speed in the direction of becoming neutral, and therewith a lesser actual motion in the same direction as before should appear immobile, and an immobile stimulus should appear to move in the opposite direction. The last of these statements is the familiar 'after-image' of movement, which has been rather thoroughly investigated (**26**). The second statement is less familiar, but it also represents a fact. Stated in another way, the after-image of movement may be just cancelled by a slow objective movement of the stimulus field in the same direction as before (**6**). But the first statement, which predicts adaptation, can not be verified so far as the writer knows by any reference to the literature of the phenomenon. Our hypothesis demands, however, that adaptation be the invariable *condition* of any negative after-effect.

A simple experiment can be made which demonstrates that adaptation to movement does occur. Two contiguous openings with shutters are cut in a screen and a moving surface is set up behind them. The observer, who should fixate a point on the screen, will find that the two fields will appear to move at the same speed when both shutters are opened at the same time. But if one field is exposed first for a short time and then the other window is opened, the first field will look slower than the second, and the two areas of movement may not coincide in apparent speed for some seconds. The difference seems to be more nearly optimal if

the two windows are close together and if their relative position is offset from the line of the movement.

Visual movement, then, is analogous to the other dimensions we have so far considered. The serial shift of the impressions from their usual stimulus-base is furthermore a localized effect in the case of movement as it is in the case of color, brightness, temperature, visual shape, and visual direction of a line.[6]

Tactual movement—An impression of movement is a datum which, like the impression of a line or edge, cuts across more than one sense department. Whatever the 'existential correlate' of a movement, it still has the quality of being *movement*—whether it is seen, or felt on the skin, or even sensed kinæsthetically. It is therefore not unreasonable that tactual movement should behave like visual movement with respect to adaptation and negative after-effect.

Thalman has shown clearly that an opposite after-effect does occur (18). If a moving belt of rough cloth is made to press against the skin for a short period and then the movement is stopped, there will be an impression of tactual movement in the opposite direction, occasionally "as clear as if the cloth had been set going backward" (p. 275). Thalman does not report that the movement slowed down during the period, but he does say that when the impression of movement was weak by reason of using a smooth rather than a rough cloth, "at times the movement adapted out and only a dull pressure remained" (p. 272). The area of the movement after-effect was sometimes clearly defined and sometimes diffuse but in general it seemed to be limited to the stimulated region of the skin. It is probable therefore that tactual movement parallels the other dimensions in possessing the functional characteristics which have been pointed out.

Taste—A number of analogous types of experience, all of them relatively simple, have now been listed. It is probable

[6] The negative after-effect, when only one eye has been stimulated, does not appear in the corresponding area of the unstimulated eye in the case of color and brightness, but does appear there in the case of curvature, tilt and movement (8, 9, 10). Movement adaptation resembles that for curvature and tilt in being incomplete.

that the list is not complete but this is not essential, since our purpose has been only to establish the generality of a number of principles which center around the phenomenon of adaptation with negative after-effect. Some dimensions, such as auditory pitch and visual size or distance, do not undergo adaptation at all. Neither does temporal duration. Others, such as cutaneous pressure and lifted weight and olfactory intensity, do show adaptation, but these are intensive dimensions and the adaptation is not accompanied by a negative after-effect. Still others, such as color, temperature and movement, fall into the type with which we have been concerned. Between these three kinds of dimensions, however, there need not be a sharp cleavage.

An example of a sense in which serial opposition is only partial and where, accordingly, adaptation is accompanied by negative after-effect in only an imperfect manner, is taste. Between the qualities of sweet and sour there is a sort of opposition, not however such that the one can neutralize the other, as in witnessed by the taste of lemonade. Nevertheless sweet and sour are so related that after adaptation to sour, distilled water tastes sweet and sweet tastes sweeter. After adaptation to sweet, it is at least true that sour is enhanced. In general, however, the after-effects of taste are more complicated and specific than this. The sensory dimensions between the four qualities of taste are more like transition-series than they are like opposition-series. The basic structure of the sense is not well understood.

Kinæsthetic right and left—Of the three dimensions of visual space, up-down, right-left, and near-far, referring now to location rather than to direction, one constitutes an opposition series, namely the series of spatial positions from left to right. The position at 'straight ahead' is neutral. This sensory dimension, either in its visual or in its kinæsthetic mode, should therefore manifest adaptation with negative after-effect. It can easily be demonstrated by means of a simple hand pointing experiment that the kinæsthetic neutral shifts in the manner demanded by theory, but a thorough experi-

ment is needed. The hypothesis should likewise be tested for visual localization.

Rotatory movement—Still another case of an oppositional dimension is furnished by the experiences of opposite rotatory movement, the stimuli for which are not the absolute angular velocities of the body but its accelerations, whether positive or negative, and their respective directions. The end of a period of acceleration, whether positive or negative, whether it teminates in uniform motion or in rest, is followed by a positive dying away of the movement-experience and then by a negative after-effect (7).

Pleasantness and unpleasantness—The hedonic series should be mentioned in this connection. There seems to be no doubt that affective adaptation occurs, nor that when this happens for one stimulus-item of an affective series there is a corresponding shift of the affective values of other items (3). Presumably the members of the series must be discriminatively related to one another for this to occur. It is suggested that the principle here is the same as elsewhere, that there has occurred a shift in the correspondence between the stimulus-series and the affective dimension.

Simultaneous or areal contrast—A fairly complete survey has now been made of sensory phenomena classifiable as adaptation with negative after-effect. No mention has been made, however, of the phenomenon of simultaneous contrast, although the possibility that this principle too might be found to operate in several sense-departments is an obvious one. Contrast is similar to adaptation with negative after-effect in that both phenomena are conditioned by the existence of opposite sensory qualities. Furthermore, both operate on the principle of a serial shift. To take an example from chromatic contrast, a large field of blue has an effect upon a smaller enclosed area such that if the latter is a less saturated blue it will appear still less saturated, if it is gray it will appear yellow, and if it is yellow it will appear more saturated. It is sometimes assumed that both adaptation and contrast are instances of a common law of contrast, one merely being

simultaneous and the other successive.[7] But this is a very superficial assumption, since their similarity ends with the fact that they both involve a serial shift in an appositive dimension. The qualitative shift in the case of contrast is a very different thing from that in the case of adaptation. The former is simply a part of the immediate perceptual process; the latter is a gradual adjustment of the correspondence between stimulus and quality to one set of conditions with a subsequent readjustment of it to the ensuing normal set of conditions. Contrast is instantaneous, like illusions or like the various 'constancy' phenomena to which it is apparently related (**14**); adaptation is a gradual process. Contrast is a matter of the relations between two spatial areas in the field; adaptation is referable to a single stimulated area. Contrast is said to be a reciprocal effect between areas, the function of which is to enhance the differences between stimuli and facilitate spatial discrimination; this may be true but it is surely not true that a negative after-effect increases the difference between two successive stimuli and thereby "facilitates successive discrimination" (**5**, p. 287). The adapting stimulus and the reacting stimulus are not more dissimilar after adaptation than they were before; the only change is a shift of both toward the other end of the scale. In fact there is no evidence that 'successive contrast' has anything at all to do with contrast between successive stimuli. With respect to simultaneous stimuli, Titchener has pointed out (**19**, p. 78) that chromatic adaptation is essentially a process tending to level all differences in the visual field, and it might be added that all negative after-effects are simply incidental accompaniments of this process.

Simultaneous, or as it might better be called, areal contrast is therefore not to be identified with adaptation and negative after-effect, although like the latter it can be shown to operate in an essentially similar way in a number of different sensory dimensions. Areal contrast, under the conditions most

[7] Von Kries (**23**, p. 239) states that the law of contrast is, in effect, this: when impressions can be arranged in a series, an element produced in *temporal or spatial proximity* to another element is displaced away from the latter. This principle, says Von Kries, applies very widely.

favorable for it, may be described generally by saying that *the perception of a non-normal quality over a large area of the sensory field is accompanied by an effect on an enclosed region of differing stimulus-value within the area altering its quality in a direction opposite to the surrounding quality.*

Areal contrast, as thus described, is a familiar phenomenon in the dimensions of color and of brightness. The facts need not be reviewed. That contrast also occurs in cutaneous temperature is less familiar, but such is the case (**11**, also **13**, p. 14). A neutral area within a ring of warmth feels cold and within a ring of cold feels warm. The same is true for visual movement (**24**, **25**) a common example being the apparent opposite movement of the moon when seen through drifting clouds. It is quite possible that tactual movement would also yield areal contrast if Thalman's technique for investigating the negative after-effect (**18**) were applied to the problem. The writer has shown that the qualities of a visual line also manifest contrast. If a straight line is seen on a background of curved lines it appears curved the other way (**8**), and if a vertical or a horizontal line is seen on a background of tilted lines it appears tilted the other way (**9**, **10**). Contrast occurs, therefore, in the dimensions of color, brightness, temperature, movement, linear shape, linear direction, and possibly in others. It does not occur in the kinæsthetically sensed dimensions of the curvature or tilt of an edge, nor in fact in any sensory or cognitive dimension in which comparisons can not be made simultaneously. It is logical that areal contrast, occurring in a sensory *field*, should be exemplified only in the visual and the cutaneous sense.

Implications for a physiological explanation—Positive after-effects, after-images, or after-excitations occur in many types of sensitivity, including some which show negative after-effects (brightness, color) and some which do not (pressure). It has usually been supposed that the positive after-effect is to be explained by an after-discharge of the same receptor-process which produced the sensation, and that like the fact of latency it is a reflection of the inertia or temporal lag of this process. Now, in the case of the after-

effects of color and brightness and of rotatory movement of the head, positive and negative effects may under some circumstances occur together, alternating in a way which suggests an oscillatory return to equilibrium. The relation between the positive and the negative effect has even been represented by a diagram showing pendular waves of excitation oscillating in time above and below the abscissa. The implication of this diagram is that the negative after-effect is, like the positive, merely an excitatory process which outlasts the stimulus—an opposite process of some sort, to be sure, but still an excitatory process. The negative and the positive effect would be cognate phenomena for both of which a rather simple physiological explanation is implied.

It will have been noticed that the present discussion of the generalized negative after-effect does not propose any physiological theory whatever to explain it. Our contention is only that the effect is a corollary of adaptation and consists of a serial shift in the stimulus-quality correspondence. If this description is correct, physiological theories, whether in terms of opposite excitatory processes or of fatigue or reduced sensitivity of the receptor, or of some other mechanism, must account for the whole description, including the adaptation, and can not assume that the negative after-effect is no more than a simple process of after-discharge. Premature physiological explanations, often without much study of the phenomenon to be explained, have been a very effective way of choking off further research in psychology.

The formula has been advanced that a persistent quality, if it belongs to the type characterized by serial opposition, diminishes in the direction of becoming normal, and that accordingly the quality evoked by any stimulus of the dimension is shifted toward the opposite quality. Negative after-effect is a by-product or incident of the primary fact of *adaptation to a norm.* This is the fact which a physiological theory must first account for. The process by which a system reaches equilibrium at once suggests itself as applicable. A state of adaptation might be a state of physiological equilibrium. But it is important to realize that the kind of equi-

librium required for an adequate theory is not an equilibrium in an isolated physiological system; there is required instead an equilibrium between inner and outer conditions, *i.e.*, in the system which includes both organism and environment. There is a shift in the *serial correspondence between stimuli and experiences*, and it can be supposed that this shift is of a sort which, in the long run, tends to keep the experiential norm, *i.e.*, the neutral quality, in correspondence with the norm of external conditions. On the stimulus side, a persistent or prolonged condition is one which perforce either is already statistically normal or tends to become so. A normal condition of the physical environment, normal temperature for example, is one which is recurrent and which is more prolonged than the abnormal conditions. Accordingly, on the experiential side, we observe a tendency for a prolonged or persistent quality to become psychologically normal—the neutral quality of its dimension. It is as if a persistent condition of the environment tended to become the normal quality of the phenomenal world—a not unreasonable assumption.[8] This general principle, then, when it operates locally by virtue of local persistent stimulation, might be the basis of adaptation. Negative after-effect would be a case of re-adaptation to the persistent condition which had previously existed. Both could be included under the formula of 'the adjustment of inner to outer conditions.' It should be emphasized that equilibrium of this comprehensive sort is not a simple physical or physiological process. Equilibrium in the sense organ or even an equilibrium of forces in the brain is not enough to explain the phenomenon.

The hypotheses which a comprehensive theory has to go on are these: that the normal quality of any dimension is the most frequent one in past experience; that the normal quality is correlated with the most stable physiological condition—the one involving the least output of energy; that the normal

[8] There is no use in debating whether the previous norm (gray, vertical, neutral temperature) tends to become the present persisting quality or whether the quality tends to become the norm, since they are wholly relative to one another. Neither alternative is an accurate statement, since the shift is one of correspondence between series, not of position within a series.

quality is correlated in the long run with the most stable and therefore the most frequent condition of the physical environment. How these and other hypotheses could be made the basis for a physiological theory of adaptation with negative after-effect, the writer does not at present know. It is probable that all norms do not have precisely the same biological basis. Some normal qualities, belonging to *sensory* dimensions, are largely the products of the sensory system itself. Such would be the 'natural' norms of gray and immobility. Other normal qualities, belonging to *cognitive* dimensions, are largely or wholly the products of past experience. An example would be the norm of a weight which is neither light nor heavy or an attitude which is neither pro-war nor anti-war. Other than this, little can be said toward proposing a theory.

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