[redacted]

October 28, 1965

Dear Paul:

Enclosed is my second and, I am afraid, my last letter report on visual factors in photo interpretation. This is a brief and sketchy version of the report on visual acuity and thresholds which, in my letter of September 24, I said I wanted to write.

What I had in mind was a fairly authoritative discussion of these subjects, to be compiled after a good deal of further reading and research, but I am compelled by circumstances to abandon the program without doing this work. Nevertheless, I thought it might be worth while to submit, in however sketchy a form, my basic view of the subject. Briefly, my view is that photo interpretation suffers severely from widespread misunderstanding and misuse of terms. This suffering is unnecessary. What is needed to cure it is not "human factors" research or experimentation with sophisticated display techniques; in fact, in the absence of basic understanding, these activities probably create as many difficulties as they solve. Instead, we need rather urgently to learn what we mean when we speak about photo interpretation.

The remarks in the enclosed report depend heavily on two basic works on vision:

> Hugh Davson, ed., The eye. Volume 2: The visual process. New York, London, Academic Press, 1962.
>
> Yves Le Grand, Light, colour, and vision. Tr. R. W. G. Hunt, J. W. T. Walsh, F. R. W. Hunt. London, Chapman & Hall, 1957.

Please see these books for a further -- and much better -- exposition of the point of view. For general orientation in the study of vision, the book by Le Grand is probably better.

I have done only cursory investigation of image reinforcement, using flicker fusion to present the observer with different random orientations of grain, which you spoke of in our recent conversation. I am simply giving my initial findings in this letter, since they do not seem to warrant composing a formal report.

I first consulted reports on a project conducted by [redacted] in 1961 to investigate image reinforcement through superimposition printing. The final report on this project is: STAT

[redacted] STAT

The authors conclude that image integration printing, which they did by superimposing three identical negatives at 4X and 10X enlargement, is capable of significant image enhancement in scenes containing areas of low-contrast detail. To me the actual improvement in their examples seems marginal or nonexistent, and I suspect their conclusion about "a true gain in information content" is more a pious hope than a fact. [redacted] STAT
STAT [redacted] manager of our [redacted] department [redacted] says that STAT there really is a gain in information with superimposition of up to eight negatives. He, however, uses the word "information" in its mathematical sense. We should guard against understanding "information" or any other term in the ordinary sense when the authors or investigators mean something else.

STAT I consulted [redacted] about the possible definition of "maximum information retrieval period" in frames per second, which you mentioned when we talked. He said that, just as one would naturally suppose, once well past the critical fusion frequency, further increases in the rate of flicker make no difference whatever in subjective perception. This is implicit in the Talbot-Plateau Law, which states that when the c.f.f. is exceeded, the apparent steady luminance of the field bears a simple relation to the light emitted during one period or cycle. This law is one of the few things about vision that can be stated categorically. It implies that the visual system averages <u>on a linear basis</u> (and therefore, presumably, on the photochemical level) the effects of intermittent light stimuli over time.

In photo-optics and photochemistry, flicker is often used as a means of observing (not eliminating, as you wish to do) the graininess of film. For this purpose the "optimum" period <u>is</u> the c.f.f., at which the grains appear to flicker but the scene as a whole does not. After that it makes no difference. There are no known subjective ill effects on the observer from fast flicker; this would be consistent with the supposition that fusion occurs on the photochemical level. (I suppose you know that slow flicker not only causes discomfort and pain, but also causes sensitive subjects literally to take leave of their senses.)

STAT [redacted] suggests that flicker projection as a means of presenting images has no advantage over either integrated printing, as was done in the [redacted] STAT project of 1961, or additive projection.

I believe that questions such as these could be better answered -- or at least more intelligently considered -- through study of the basic phenomena of flicker, which are rather well known, than through ad hoc experimentation. These basic phenomena are well discussed in the books by Davson and Le Grand and the references they cite. A more recent discussion is:

> H. E. Henkes and L. H. van der Tweel, eds., Flicker: proceedings of the symposium on the physiology of flicker. The Hague, 1964.

Unfortunately I don't understand much of this book and can't review it very intelligently.

Along with the little report on acuity and thresholds, I am enclosing a copy of the notes I have collected so far in the program, with references which will serve for an initial bibliography. My notes are far from exhaustive but do indicate the contents, point of view, and possible usefulness of each source. The references include those I cite in this letter.

May I say, Paul, that I have greatly enjoyed talking with you and sincerely regret having to drop the program just when it was beginning to get interesting? If it should be desirable you can always reach me through [redacted] STAT

STAT [redacted] or, perhaps more directly, through my former supervisor,

Sincerely,

[redacted] STAT

VISUAL ACUITY AND VISUAL THRESHOLDS

Pirenne, an authority on visual psychophysics, states,[1] "A tendency to give visual acuity an ontological status (that is, to treat it as if it had reality) has sometimes led to confusion." Confusion exists in the field of photo interpretation, not only over visual acuity but, still more, over the analogous concept of visual sensitivity or "threshold." If it were clearly recognized that these terms do not denote objective facts, but rather symbolize statistical probabilities, much less nonsense about "resolution" and "threshold of detectability" would clutter the literature on photo interpretation. In this brief paper I will not attempt to explain the distinction, which is beyond our immediate concern, between a fact and a figure of speech, but will merely discuss the nature and experimental treatment of visual acuity and visual thresholds. Correct understanding of these terms is essential for any intelligent view of photo interpretation and its techniques.

Visual acuity, or form discrimination, is defined as the reciprocal of the angle (in minutes) subtended by the smallest detail which can be seen under given conditions. This is obviously a purely operational definition; in fact there are as many different "visual acuities" as there are types of test object, and there is no reason to expect that acuity values will be the same or vary in the same manner for different test objects -- still less for different photographic images. The problem of acuity is different, for example, when the eye must detect one or several gaps within an object, such as the Landolt "C" or a grating of equidistant parallel bars, and when the eye must simply detect an object, such as a black dot or line, on an

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1 in Davson, Hugh, ed., The eye. Volume 2: The visual process. New York, London, Academic Press, 1962.

illuminated field. In the latter case the object need only produce a detectable difference of retinal stimulation by comparison with the field; but in the first case a detectable difference must be produced between the stimulation corresponding to the gap and that due to other parts of the test object itself.

In experiments with gratings of parallel black bars, the factor which sets the limit to acuity seems to be, not the capacity for intensity discrimination of rows of adjacent cones, but rather the anatomical separation between the cones. Maximum acuity, therefore, is reached when all single-cone receptors are active. As luminance is increased, more and more central parts of the retina are used to detect the t4st object. Peripheral retinal regions, though more sensitive to light (having lower "threshold"), are less accurate for acuity, as is implicit in the duplicity theory.

At high light intensities, lights of all wavelengths undoubtedly stimulate all types of central cones, because of the great width of their spectral sensitivity curves, so that peak sensitivity differences between cones become unimportant and acuity values are the same.

In the center of the fovea, where the best visual acuity is mediated, the "blue" mechanism is relatively insensitive. Then central acuity must be mediated by the other cone mechanisms, which at high intensities may function as single-cone units. When they are all sufficiently stimulated they may yield an acuity corresponding approximately to the distance between centers of cones. High luminances of any spectral composition should be able to stimulate all the cones and thus would always lead to the same limiting acuity values. Thus the existence of cones of different spectral sensitivity does not necessarily imply that the limiting acuity value for high luminances must be smaller for narrow spectral bands than for white light.

The visual acuity of cone mechanisms with changing luminance has been isolated by the Stiles two-color method. In passing from low to high intensity, the appearance of the test stimulus just above the threshold changes: its outline loses sharpness and the apparent color becomes purplish instead of blue or blue-green. This effect suggests that the "blue" mechanism has a lower acuity than the "green," at least for light intensities near threshold; at higher intensities the "green" mechanism takes over because it is more accurate in discriminating detail (see curves pp. 190-191 in Davson, 1962).

The practical bearing of the above information is that two-color isolation and other acuity experiments described in the literature must be carefully examined, and additional experiments must be performed by trained psychophysicists under controlled conditions, before any conclusions are drawn as to the usefulness of colored lights, for example as light sources in projection viewers, in working situations. Moreover, the many other factors which govern the perception of color, such as adaptation, constancy, and emotional effects, must be given due consideration. In practical circumstances any one of these factors may be at least as important as acuity differences.

Thresholds of seeing are not sharply defined. Even in controlled experiments it is impossible to set the apparatus at a definite intensity value, above which the stimulus is always seen and below which it is never seen, even by the same observer. Instead, there is always a range of uncertain seeing, which must be caused by a combination of variations in the observer -- biological or psychological or both -- and physical fluctuations in the stimulus itself.

It is, therefore, necessary always to define the experimental threshold intensity as that at which a given test object or light is seen with an arbitrarily chosen proportion of exposures, for example 50 or 55 per cent. (If the threshold were taken to denote an absolute value, this would mean that the observer would not see a "threshold" stimulus nearly half of the time, a frequency of failure which could not be tolerated in practical visual tasks.) The experimentally defined threshold is mediated by the periphery of the dark-adapted eye, that is, the most sensitive retinal region in its most sensitive condition.

What variations contribute to the "range of uncertain seeing" which is so important in setting demands for visual tasks?

Quantum variations of the stimulus. The quantum theory states that any emission or absorption of radiation takes place in a number of individual events, in each of which a single quantum of energy is exchanged. When studying quantum events we are dealing only with statistical probabilities, such as the probability of absorption of a quantum of light by a given retinal receptor. If experimental conditions are held constant, the mean number of quanta absorbed by the receptor in many trials will be constant; but the actual number will vary and is impossible to predict for any given trial.

This variation occurs with all stimuli, including intense ones, but with near-threshold stimuli, which themselves consist of only a few quanta, the variation is proportionally more important, and often makes the difference between the observer's seeing and not seeing.

Individual variations. Purely quantum fluctuations would be random and would give independent results in successive trials. Experimental results, however, show that successive responses are not independent, so part of the uncertainty of seeing must be due to variations in the observer. These individual variations combine in a complicated manner with quantum fluctuations and cannot be studied in isolation, but can sometimes be inferred from experimental conditions. Indeed, they can often be observed in everyday experience.

Variations of the statistically defined threshold occur in the same subject from day to day by as much as a factor of two. Untrained subjects have a large range of uncertain seeing (or shallow frequency-of-seeing curve) but improve with practice. When a subject is tired, unwell, or out of sorts, his range of uncertain seeing may increase. But other large variations occur without observable cause; these may be due to unknown long-term variations in the eye, the visual pathway, and the brain.

In addition to variations in the same observer, the statistically defined threshold values of different subjects, all with "normal" vision, may differ by a factor of from five to ten. Night-blind subjects have a much higher threshold than this "normal" range, but no subjects have thresholds very much lower.

What is the lowest light stimulus necessary for vision? Visual thresholds have been measured under three main sets of conditions:

(1) A test field of very large angular diameter, presented in long exposures. This allows both temporal summation within individual receptors and spatial summation between receptors. Quantum fluctuations will lead to random concentrations of quanta in both space and time. For this reason, during a long exposure, one or a few retinal receptors may absorb within their summation time enough quanta to be stimulated. The large field is

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probably "seen" when a few quanta have been absorbed in the receptive field of an optic nerve fiber within its summation time; or stimulation of more than one optic nerve fiber may be required. Tests with a large field and long exposures lead to the lowest value of retinal illumination necessary to cause a perception of light. Subjectively the field looks blurred; the subject cannot distinguish between a large luminous circle and each of its component halves presented separately in flashes.

(2) A test field of very small angular diameter, presented in long exposures. This leads to the lowest value of radiant flux which must enter the eye to make a light source visible.

(3) A small test field, presented in brief flashes of, say, 0.001 sec, with the retinal position of the image controlled by the use of a fixation point. When the most sensitive region of the retina is used, this method leads to the smallest values of the total amount of radiant energy that can cause a visual sensation.

A typical threshold experiment introduces blanks in a random series of genuine light flashes. Most (but not all) experimental subjects report a few blanks as "seen." In one experiment the proportion of blanks "seen" varied between zero and 0.78 per cent according to the subject. The statistical treatment of false "seens" is affected by the criterion of visibility used by the subject: if a subject changes his criterion of visibility from "seen" to "possibly seen," and reports as "possibly seen" 1 per cent of the blanks in a series, then the statistically defined threshold value becomes 25 per cent lower. Some experimenters believe that false "seens" are not cases of statistical-biological uncertainty, but rather represent conditioned afterimages produced by the sound of the shutter to which the subject is accustomed.

The threshold, then, is not a line separating "seen" from "not seen," as the figure of speech implies and as many photo interpreters tacitly assume. (Most of us tend implicitly to regard metaphors as if they denoted real objects, and the average photo interpreter has heard and uttered the word "threshold" as though it did have a literal sense so often that he is surprised, even incredulous, when reminded that it is a metaphor.) The threshold is a statistical central tendency, which is only useful when understood to be an abstraction -- not an objective measurement, let alone an objective fact. The only objective measurement we can record is that observer A, under conditions x, in trial 3, saw, barely saw, possibly saw, or did not see stimulus y. It does not follow that stimulus y, if "barely seen," represents the "threshold" for conditions x, or even for the individual observer A under conditions x. It does not even follow that stimulus y, if "seen," was there at all. The fact that the most reliable subjects, under the best experimental conditions, sometimes "see" stimuli when none are present, has an obvious bearing on the reliability of uncontrolled answers (that is, answers unsupported by ground truth) in difficult tasks of photo interpretation. This bearing is particularly significant in time-limited tasks when the observer cannot make several independent trials, but must report an answer immediately.

One statistical aspect of the experimental threshold is especially relevant to photo interpretation: probability summation in binocular seeing. If we neglect individual variations and assume that the probability of seeing is entirely determined by quantum fluctuations, then if the probability of a subject's seeing a stimulus (with one eye) is one-half, the probability that one of two subjects will see it (with one eye each) is three-fourths. Similar results are obtained for the two eyes of one subject, which behave as though they belonged to two different persons; there is no evidence of physiological summation or inhibition between the eyes. One experimenter, however, found binocular frequency of seeing significantly greater than would be expected from probability summation alone. This again may be due to a change in the subject's psychological criterion of visibility or state of confidence: he may report as "seen" a stimulus which is really "barely seen" by both eyes.

Probability summation, perhaps supported by increased confidence in the observer, seems a far more direct and relevant explanation of "binocular refinforcement" in photo interpretation than supposed differences in tone or grain patterns between two photographs. These arguments have always seemed to me particularly naive.

Applications. Attempts to use, in working situations, information such as that sketched above must respect two warnings (besides the obvious condition that the information must first be understood).

(1) Visual performance in practice is notoriously hard to correlate with performance in laboratory tests. Correlations may exist, but fail to be detected because of variations introduced by complex biological and psychological factors. In any case, correlations between experiment and practice must be stated and criticized by trained experimenters.

(2) Experimental thresholds, no matter how rigorously defined, constitute only one aspect of the study of the eye. The reader should memorize the following words of Le Grand[1]: "It would clearly be absurd to consider conditions of work in which the subject is kept close to the threshold; he would tire very quickly and his performance would be lamentable." This author seems to have had photo interpretation in mind.

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[1] Le Grand, Yves, Light, colour, and vision. Tr. R. W. G. Hunt, J. W. T. Walsh, and F. R. W. Hunt. London, Chapman & Hall, 1957.

STAT

Le Grand, 1957

applica-
tions

Preface: point of view is essentially that of the physicist. Considers eye as receptor of radiant energy. (Note L.G. has publ, in Fr., a first vol. considering eye as optical instrument, and a third (1956) in which 2 points of view are brought together. This Engl. translation is the 2nd vol. of 3).

No desire to ignore the physiological aspect, which alone can explain the functioning of the retina and the nervous relays, but the accent is definitely a physical one, and the aim is to give to opticians, to those who construct visual apparatus, to illuminating engineers, architects, etc., as much information and as many numerical data as possible concerning response of eye to radiation.

This physical approach, purely experimental & stripped of all theory, forms Sec. A. of the book. Sec. B contains such elements of anatomy, physiology and psychology as are necessary to understand the various visual theories that have been suggested from time to time.

Sci. Am.
Aug. 1950
" Eye & camera" by George Wald

vision
physiol

More we learn about mechanism of vision, more pointed & fruitful has become comparison with photography. Relation between eye & camera goes far beyond simple optics, involves much of essential physics & chemistry of both.

Each grain of silver bromide in exp. film blackens completely or not at all; grain made susceptible to devel by absorption of one or a few quanta of light. Similarly, cone or rod is excited by light to yield maximal response or none. Abs. of quantum of light by light-sensitive molecule in either structure might convert it into a biol catalyst, or enzyme, which could promote further reactions that discharge receptor cell. Functionally eye is one device in bright light and another in dim. In dim light ceases to adjust focus, resembles cheap fixed-focus camera. Vertebrate eye is long-range high-acuity instrument, useless in short distances at which insect compound eye resolves greatest detail.

Yellow color of lens and ~~high~~ sensitivity shift toward higher wavelengths in bright light compensate for chromatic aberration of eye, which greatest in blue & violet. Rods have max sensitivity about 500 mu, cones 562. Also fovea & region of retina around it are colored yellow in man, apes & monkeys. Yellow patch removes for central retina the remaining regions of spectrum for which color error is high.

Normal human color vision seems compounded of 3 kinds of responses. Simplest assumption is that 3 light-sensitive pigments. In chicken & turtle, oil globules in cones are 3 colors: red, orange, greenish-yellow.

Bleaching of rhodopsin is composite process, ushered in by light reaction that converts rh. to highly unstable product; this decomposes by chem "dark" reactions that do not require light. As in photography, light produces a latent image.

Under natural conditions, daylight vision is largely mediated by cones, night vision by rods. Best region of retina to be used is more eccentric when illumination is lower; trained subjects can learn to use best retinal region under given conditions.

In daylight, foveal vision gives highest acuity and normal eye sees colors. Fixation reflex brings image of objects looked at onto fovea. At illum level of dark night, fovea is blind, only peripheral vision operative, acuity much lower than in daylight & colors are not seen.

Recent study of directional sensitivity has given further support to duplicity theory.

Purkinje phenomenon: relative brightness of objects appears to change when general level of illumination altered, e.g. in dim light blue objects look very much brighter than red. Because of diff spectral sensitivity of rods & cones: rods relatively more sensitive than cones to blue end of spectrum. (This experiment works only if eye adapted to low illumination; otherwise neither red nor blue may be seen.)

Purkinje phenomenon may lead to considerable errors in visual measurements expressed in photometric units. Only when rel spectral comp of two lights same can visual photometry be used to equalize their physical energies.

Light from night sky much richer in long wavelengths than daylight. Yet differently colored objects still refl light of diff spectral composition, so color vision on dark night should not be physical impossibility. Example: color photos in astronomy: study spectral comp of light emitted by celestial bodies, "color" of which never directly seen.

At very low illum, eye becomes incapable of dist betw lights of diff spectral comp, only diff seen being those of brightness. Light too faint to stim cones; rod system only functioning; this system incapable of responding in qualitatively diff manner to light of diff wavelengths

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Davson 1962 — duplicity

Why has rod system not developed powers of wavelength discrimination? Probably connected with fact that visual acuity becomes so poor on dark night that wave dis would be of no biol value. Color of small objects, or of details, is of significance, not color of sky or general color of foliage. When small details can no longer be distinbuished, color vision loses its point. Also, quantum ~~xxxx~~ fluctuations would set limit to accuracy with which spectral ~~diff~~ distributions could be differentiated at low light intensities, even if necessary physiological mechanisms existed. Even in cone vision, confusions occur about subjective colored appearances of nearly monochromatic stimuli of near-threshold intensity. Probably due at least partly to fluctuations in nos. of quanta acting on spectrally selective cone mechanisms.

Davson 1962 — duplicity (direc.sen)

Luminous efficiency of light ray enetering eye is dependent on point in pupil through which ray has passed. (Stiles-Crawford effect, disc. 1933.) Essentially a property of cones; for rods, directional effect absent or very small for range of angles of incidence accessible through pupil. Before this, generally supposed that apparent brightness of surface determined by total flux of light entering pupil. However, now est. that a given flux of light entering through outer zones of pupil contributes less to apparent brightness than equal flux entering near center. Near edges of (artificially dilated) pupil, value of relative effiency reduced to a third or even less of what it is near center.

Explanation: for all positions of entry, rods are stimulated to same extent, since they are almost non-directional. But cones in retinal area receiving field image are less strongly stim for peripheral than for central entry. Thus when periph entry used, provided field luminance properly adjusted, cones are not stimulated at all, or stim insufficient to cause sensation of color. Colorless sensation received is mediated through the rods.

Stiles-Crawford effect is valuable method of separating relative contributions of rods & cones in many phenomena.

Magnitude of directional effect varies with wavelength. Change of color in fovea of physically homogeneous radiation: Stiles-C effect of the second kind. Is distinct from intensity effect and might arise in a different way.

In extrafoveal test areas, large diff betw curves at high and 0 field luminanance. Those for bright field approximate in shape to foveal curves; those for dark-dapted eye have almost flattened out, so that lum efficiency of light pencil becomes almost independent of point of entry through pupil. Foveal curves nearly same for high and 0 conditioning luminance, i.e. pronounced direc. sens. for both conditions.

OVER

Weale (1961): Varying thicknesses of eye lens, which contains yellow pigment, may generate for light ofshort wavelength a difference betw the Stiles-C effectx as normally measured and the true retinal effect; this would make the true retinal directional effect materially larger in the blue than the measured effect. Rods may also have direc sens at short wavelength.

duplicity
(lum.eff)

Davson 1962

Cone vision can be isolated by confining stimulus to rod-free center of fovea. There is no region of retina containing rods only; but rod vision can beisolated to great extent by using low light intensities with fully dark-adapted eye, provided stimulus is not restricted to central part of pupil. By peripheral entry, test stimulus in dark-adapted parafovea can be made to act upon rods alone. For pediph vision, using natural pupil, there is an intermediate range of intensities where rods and periph cones both appear to be active, and where lum effic shifts from rod to cone curve as intensity increased.

Range of low luminanace levels ("scotopic") refers largely to rod function, intermediate ("mesopic") to combinations of rod and cone function. Photopic range (day-light) refers to cone function, but when periphery used in this range not clear whether rods are entirely out of action. Eye works over total range of luminance of moe than 1 to xx 10^{10}.

Retinal rods contain photosensitive substance "rhodopsin" which bleaches under action of light. Strong dependence on wavelength of sensitivity of rod system probably largely due to fact that rhodopsin absorbs some wavelengths more readily than others. Abs max in blue-green, where also max sensitivity; very little in deep red, where rod sensitivity also low.

Absorp spectrum of human rhodopsin has been measured in vitro on extracts. For purely optical reasons, shape of abso spectrum of a bubstance varies with optical density (log to base 10 of ratio of intensity of incident light by intensity transmitted) of the absorbing layer. Close corresp with rod quantum sensitivity at retinal level. This corresp sufficiently good to support theory of rod sensitivity curve. This was very imp when no pigments yet extracted from human cones. (see influence of wavelength on uncertainty of seeing) curves p. 75 & 76, max. about 500 mu

duplicity
(lum.effic)

Davson 1962

Max foveal sensitivity about 560 mu; periphery about 507 (for 1-sec flashes in dark-adapted eye). At foveal threshold, color of test field often seen & varies with wave-length. For these conditions the fovea is lesssensitive than periphery except 675-740 mu where about same. With shorter flash, 0.04 sec, cone vision favored because temporal summation smaller than for rod vision. Here forvea becomes more sensitive than periph above 600 mu.

Response of the fovea must be largely determined at any wavelength by the most sensitive cone mechanism for this wavelength. No evidence of genuine physiological summation between cone mechanisms.

It would be completely wrong to think that the luminous effiemcy of radiation must always correspond either to the scotopic or to the photopic function (p. 88)

Davson 1962

p. 94, typical curve for course of dark adaptation in near periphery. At first threshold drops rapidly, then from about 5-7 minutes levels to plateau. This first part of curve is cone branch. After cone-rod transition time (when appearance of white field changes from violet to colorless gray), another less rapid drop; from about 15 min, change in threshold much slower, after 25 min a further stay in the dark leads to little further change. This second part of curve is rod branch. Under conditions of exp, threshold is about 10,000 times smaller at end than at beginning of dark adaptation. Cone threshold is about 500 times higher than final rod threshold.

In case of fully dark-adapted periphery, both rods & cones become active when submitted to intensities above cone threshold; rods most probably out of action over extent of time covered by cone curve of dark-adapt experiments. Important differences from one (presumably normal) subject to another; but general course of adaptation, esp. the cone-rod transition time, remains very similar from one sub to another. Indiv final rod thresholds cover range of 1 log unit, i.e. about 1 to 10.

Prolonged exposure to sunlight produces temporary and cumulative effects on night vision. After several hours e.g. on beach, whole night of dark adaptation is not sufficient to bring sensitivity to previous level. Several days at lower illum may be required.

When most of rhodopsin has been bleached in living human eye, takes about ½ hour to regenerate completely. Cone pigment takes only 7 min to regenerate. Some important link betw [illegible]neration of visual pigments and that of dark adaptation. In normal subjects rod-cone transition time is dark-adaptation time at which 90% of rhodopsin is present in rods, no matter how extensive was initial bleaching.

Night vision: because of complex psychological factors which cannot be reproduced in lab, visual performance in practice may be difficult to correlate with lab tests. Correl may exist but fail to be detected because of psycho variations.

threshold definition

Davson 1962

Statistical definition. Threshold is not sharply defined on light intensity scale. Thus is not possible to set apparatus at definite intensity above which light always seen and below which never seen; range of uncertain seeing varies with experimental conditions. This variation must be caused by combination of biol variations and physical fluctuations in light stimulus itself. Experimental threshold intensity must therefore be defined as that intensity at which test field is seen with arbitrarily chosen % of exposures, for example 50 or 55%, Value of 55% is convenient for theoretical reasons.

Individual variations. In normal subj under same conditions, variations of statistically defined threshold occur from one subject to another, and also in same subject from day to day, by as much as a factor of two. These must be caused by long-term variations in properties of eye media, retina, and visual pathway. Threshold tends to increase with age.

Statistically defined threshold values of different "normal" subjects may differ by factor from 5 to 10. Night-blind subj have much higher threshold, but no subjects have thresholds very much lower than normal range. Measurements discussed in this chapter 6 refer to presumably normal subjects, periphery of dark-adapted eye.

Types of threshold measurement. (1) test field very large angular diameter, presented in long exposures; this leads to lowest value of retinal illum necessary to cause a perception of light. (2) test field very small angular diameter in long exposures; this leads to lowest value of total radiant flux which must enter eye to make a light source visible. (3) small field presented in brief flashes, e.g. 0.001 sec, with retinal position of image controlled by fixation point. When most sensitive region of retina used, this method leads to smallest value of total amt of radiant energy that can cause a visual sensation.

threshold reliability

Davson 1962

Hecht emphasized reliability of 3 subjects of main experiments, who did not report as "seen" the blanks which introduced in random series of genuine light flashes. Baumgartner used many blanks to study reliability: % of blanks reported "seen" varied between 0 and 0.78% according to subject. Two subj who never reported blanks "seen" gave 55% threshold values between 85 and 114 quanta.

According to Barlow (1956) a subj can change his criterion of threshold visibility from "seen" to "possibly seen," subj then reporting as "possibly seen" 1% of the blanks, with result that statistically defined threshold value becomes 25% lower.

To avoid influencing subj and responses in unpredictable ways, flashes must be presented in random series of intensities unknown to subject.

(see later on, where opinion stated that false "seen" are cases of conditioned afterimages, i.e. conditioned on sound of shutter.)

 threshold probability summation

Davson 1962

Assuming that uncertainty of seeing entirely determined by quantum fluctuations: if probability of one subj seeing stimulus is ½, probability that one of two will see (with one eye each) is 3/4.

Similar results obtained for two eyes of one subj using brief small flash in periphery. Probability of seeing when both eyes used follows steeper curve than probability for one eye only. Two eyes behave as if belonged to two different persons; no evidence of either summation or inhibition between them. Collier (1954) however, found binocular frequency of seeing significantly greater than that computed from uniocular frequencies on probability summation basis. This may be due to subject's criterion of visibility being different in these experiments. May report flash as "seen" when it is "barely seen" by both eyes.

fatigue

Light, colour and vision, by Yves Le Grand. Tr. R.W.G. Hunt, J.W.T. Walsh, F.R.W. Hunt. London, Chapman & Hall Ltd., 1957

In chapter on "luminance difference thresholds": The idea of an absolute threshold, or of a difference threshold, covers only one aspect of the study of the visual receptor: it would clearly be absurd to consider conditions of work in which the subject is kept close to the threshold; he would tire very quickly and his performance would be lamentable. Many investigations have been carried out to establish the supra-liminal conditions necessary in order to carry out a given task with comfort, but such work falls outside the scope of the present book. (p. 271-72)

performance

Davson 1962

Because of complex psychological factors which cannot be reproduced in laboratory, visual performance in practice may be difficult to correlate with lab tests. Correlations may exist, but fail to be detected because of variations introduced by psycho factors.

visual acuity

Davson 1962

Visual acuity is defined as reciprocal of angle, in minutes, subtended by the smallest detail which can be seen under given conditions. This is a purely operational definition and there are in fact as many different "visual acuities" as there are types of test object. A tendency to give visual acuity an ontological status (that is, to treat it as if it had reality) has sometimes led to confusion. There is no reason to expect that acuity values will be the same or vary in the same manner for different test objects.

Problem of acuity is different (1) in the case of test objects with one or several gaps which must be detected by eye, or a grating of equidistant parallel bars, and (2) in case of simple detection of an object, such as a black dot or line on illum field. In case (2) it is sufficient for object to produce detectable difference of stimulation by comparison with surrounding field, whereas in case (1) a detectable difference must be produced betw retinal stimulation corresponding to gap and that due to other parts of the object itself.

In case of grating consisting of parallel black bars, is possible to produce "deterioration) of image by using a grating in which bars half as wide as before, but same number of bars per unit angle. Differences of illumination in image then reduced to one-half previous value, while general shape of smooth periodic variations of illum across image remains the same. Yet the eye resolves the grating as well. Conclusion: factor which sets the limit to acuity in these experiments is not capacity for intensity discrimination of rows of adj cones recieving blurred images of black and bright bars, but anatomical separation betw the cones. Maximum acuity must be reached when all the single-cone units are active.

Limiting acuity value about same for blue, red, and white light. At high intensities lights of all wavelengths probably stimulate all types of central cones, so that sensitivity diffs betw cones may become unimportant with regard to acuity.

In acuity experiments, subjective obs showed that more & more central parts of retina used as luminance increased. Acuity values up to about 1/8 obtained with peripheral regions of decreasing eccentricity; betw 1/8 and 1/1.4 using foveal regions some distance away from the center; higher values using regions near or at the center. Thus it appears that more peripheral retinal regions are more sensitive to light but less accurate for acuity. In the periphery this is readily understandable if there is increased spatial physiological summation as move away from central fovea. Retinal units consisting of incr numbers of receptors become increasingly sensitive in terms of light flux per unit area, whereas constitute a coarse functional mosaic in terms of angular size of test objects. In the fovea the increase in cone size as move away from the center should lead to the same result, even if no summation occurred between single cones.

Vision of steadily exposed objects under natural conditions must be dependent on eye movements. Physiological mechanism of acuity may then be different from that involved in case of brief flashes. Slight eye movements must be inefficient at scotopic levels because of indefiniteness of stimulus itself.

Subjective effects of contrast are probably due to inhibitory interactions, but in many cases such effects seem to be useless or misleading optical illusions. Subjective contrast as a rule is observed only when the relevant differences in the external field are easily seen. There is no evidence that subj contrast, as such, helps in the detection of nearly liminal differences -- but presence of inhibitory mechanisms underlying contrast may, indirectly, do so.

Acuity of isolated cone mechanisms. Curves p. 190 suggest that "blue" mechanism acuity reaches a plateau, the "green" mechanism taking over at higher intensities because it is more accurate in discriminating detail.

Brindley (1954) experiments. Best visual acuity under ordinary conditions is mediated by center of fovea. Here the "blue" mechanism is relatively insensitive. O e of possible explanations for this would be that there are fewer "blue" cones in this region than near the edge of the fovea. If so, central acuity would be determined largely by the other cone mechanisms.

Because of great width of spectral sensitivity curves of the various cone mechanisms (see ch. 14) high luminances of any spectral composition should be capable of stimulating all these cones and would thus always lead to the same acuity values. These are only speculative considerations, but at any rate show that there is little reason to suppose that existence of cones of different spectral sensitivities implies that the limiting acuity value for high luminances under ordinary conditions must be smaller for narrow spectral bands than for white light. At high intensities, mechanisms ~~xx~~ other than blue may function as single-cone units, so that, when all sufficiently stimulated, may be able to mediate an acuity corresponding to the inter-center distance of the cones.

Acuity of rod monochromat. At scotopic luminances when most accurate part of retina is used, relation bet luminance & acuity similar to normal, but acuity fails to increase at higher luminances as it does in the normal. Part of the curve which attributed to cones or cones-rods is missing.

uncertainty

Davson 1962

Experiments with large field & long exposures give steep frequency-of-seeing curves & range of uncertain seeing of order of 1 to 2. Shares of biological variations and quantum fluctuations cannot be determined with certainty. But even if uncertainty range were entirely due to biol variations, could not exceed 1 to 2. This suggests that, in the small brief flash experiments also, biological variations may not have exceeded range of 1to 2, whereas observed range is of order of 1 to 10.

Biol variations become combined in complicated manner with quantum fluctuations and with possible physiol omplications; cannot be studied in isolation. Non-independence of successive responses to flashes indicates that biol variations do occur in some exp; purely quantum fluctuations would be random and lead to independence in successive trials.

When subj is tired or unwell, range of uncertain seeing may increase. Some untrained subj give very shallow frequency of seeing curves, which become steeper with practice. This must be due to changes in extent of biol variations. In properly conducted experiments it has proved impossible to obtain variations smaller than the min predicted by the quantum theory.

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threshold
absolute

Davson 1962

Because of quantum properties of light, actual physical light stim absorbed by retinal receptors varies from one trial to another, even when all exp conditions held constant. Smaller no. of quanta, more important the fluctuations.

Quantum theory states that any emission or abs of radiation takes place in a no. of indiv discrete events, in each of which a single quantum exchanged. When studying quantum events we deal only with probabilities, such as prob of abs of a quantum by a given retinal receptor. Under constant exp conditions the mean no. of quanta absorbed by the rod, in many trials will be constant. But actual no. will vary & is impossible to predict for any given trial.

Davson 1962

threshold
absolute

Average absolute threshold for large field in white light, for young subjects: 0.75×10^{-6} cd/m^2. This is the luminance of a perfectly diffusing surface illum by source of 1 candela placed 650 meters away, assuming no loss of light in intervening medium. Equivalent to retinal illumination of 4.4×10^{-5} scotopic trolands. Pirenne et al 1957. Abs threshold of cats measured by behavioral method between 0.18 and 0.76×10^{-6} cd/m^2. Thus the most sensitive human subj have thresholds within range of cat threshold.

Amt. of light of 507 mu equiv to above amts of white light can be calculated from scotopic luminous efficiency function. Direct experimental comparison with spectral band in green & with white light confirms this calculation.

At the 50% threshold, less than 0.3% of rods can on average be affected by light during full ½ minute exposure; 99.7% fail to absorb even a single quantum & are totally unaffected by stimulus. The large field is probably seen when a few quanta have been abs in the receptive field of an optic nerve fiber within summation time of this retinal functional unit; or stim of more than one such unit may be required for threshold vision. Quantum flucs will lead to random concentrations of quanta both in space and time. For this reason, during 15 sec exposure, one or a few retinal units receiving image may abs within its summation time enough quanta to be stimulated. Summating properties of all units involved are insufficiently known to make accurate calculation possible. Subjectively, large field near threshold looks blurred; subj cannot distinguish between large luminous circle and each of component halves presented separately in [illegible].

"focal length"

Davson 1962

Anterior chamber behind cornea (section of eye p. 330) is filled with aqueous humor of refractive index 1.33. Cornea and aqueous humor together have refractive power of about 43 diopters, thus constituting the main refractive surface of the eye.

(A one-diopter lens has a focal length of one meter, a 10-diopter lens, one of 0.1 meter, and so on, diopter being the reciprocal of the focal length in meters.)

Behind anterior chamber is lens, a double-conves body, the form and hence refractive power of which can be varied by action of ciliary muscle. The total power of the resting eye (when relaxed for distant vision) is about 60 diopters. In early life when lens soft and pliable a further 14 diopters of power can be produced by max effort of ciliary muscle to accommodate vision for near objects.

Refractive power of eye is not independent of wavelength: long w.l. light refracted more than short. A human eye focused for 600 mu is about ½ diopter too strong for perfect focusing of 800 mu and about 2 diopters too weak for perfect focusing of 400 mu. This chromatic aberration becomes worse for shorter wavelengths. Thus axial aberration at 300 mu is 6-7 diopters. Inability to focus light of w.l. 300 mu and lower limits use of these wavelengths for vision: refracting eye (unlike compound eye) is only feebly sensitive to these radiations.

flicker

Davson 1962

Flickering appearance of a light source which extinguished at regular brief intervals disappears when no. of extinctions per sec becomes large enough. Critical fusion frequency (no. of complete cycles of light & darkness per sec) lowest freq at which this happens. Luminance of flickering light is main factor that influences c.f.f.: at high luminances may exceed 100, in most lab experiments rarely more than 60. When c.f.f. exceeded, apparent steady luminance of field bears simple relation to light emitted during one cycle: ratio of time of exposure to total time. At lower frequencies light no longer appears steady and peculiar subjective effects often observed (see Le Grand). For instance, if wide colored field of high luminance, flickering at 40-50 per sec, presented in periphery while fixation maintained, field looks white shaded with violet. When flicker suddenly changed to steady illum, color appears with high saturation. Critical fusion frequency may be regarded as measure of time-resolving power of the visual system. It depends on luminance of field, area of field, region of retina stimulated, light-dark ratio in each cycle, state of adaptation of eye, and other physiological & psychological factors.

Retinal position. For eccentricity 0, area stimulated contains mainly cones; results give simple curve which probably corresp to cone function. For eccentricy 5° curve shows marked division into two branches; low-intensity branch is ascribed to rod function. At lowest illum, flicker is more easily detected by periphery than by fovea.

Wavelength. At higher illum, results for all spectral bands fall roughly on same curve. Low-intensity branch extends toward lower illum as w.l. becomes shorter. (p. 209) For violet (450 mu) and blue light (490 mu) over certain range of low illum, the c.f.f. is almost independent of retinal illum. Over this range the rod system is working near its max efficiency with regard to detection of flicker. At highest illum, c.f.f. for cone branch also becomes approximately constant.

flicker

Davson 1962

Binocular flicker. When both eyes stim together, c.f.f. is higher for flickering fields which are in phase than for those out of phase, but diff is not large. When intermittent stimuli are out of phase, total flux of light reaching visual system is constant. Any simple hypothesis of summation between eyes, according to which flicker should never be seen with out-of-phase binoc stim, is thus ruled out. Yet, as c.f.f. is not sharply defined on frequency scale, possibility remains that binocular effect may be explained on basis of probability summation. Peckham & Hart (1960) conclude that binoc response to flicker involves some kind of facilitation between two monoc responses, which takes place at a neural level beyond the chiasma (intersec of optic nerves).

flicker
color

Flicker: proceedings of symposium on physiology and clinical electro-retinography, Sept. 1963. H.E. Henkes & L.H. van der Tweel, eds, Hague, 1964.

Book contains many detailed articles on psychophysics as well as physiology of flicker. In article by C.R. Cavonius "Color sensitive responses in the human flicker-ERG" pp. 109-110:

Changing adapting field wavelength causes selective effects in spectral sensitivity of human ERG; these effects are in the expected direction, i.e. to selectively depress responses to stimuli at or near wavelength of adapting field. But effects are so slight that of little value in quantifying nature of fundamental color receptors.

Easier to account for results in terms of model which uses separate system to mediate brightness, either by unique brightness receptor or by recoding of signals from color receptors. In either case the ERG resp. to fast flicker would be primarily a measure of activity in brightness system, which, since not concerned with hue, is unaffected by selective adaptation of color systems.

A final explanation for the lack of color explanation is based on one of the most compelling argumments for separate brightness and color systems: fact that color flicker and brightness flicker fuse at very different frequencies. If 2 colors alternated & intensities properly adjusted, may be made to fuse at rate under 20 flashes/sec. This suggests that color mechanisms may respond poorly to fast flicker. Le Grand & Geblewicz 1937 found that colored field presented extra-foveally & flickered at 40-50 flashes/sec lost saturation and turned white. If flickering field suddenly replaced by steady field of same color, this now appeared more saturated than comparison field which never flickered. They suggest that the color mechanism may be inhibited by flicker. (Note: this last appears probable, but theories by Cavonius on separateness of brightness and color mechs, on basis of different frequencies of fusing, seem to be non seq.)

cf. Le Grand, Y. & Geblewicz E., C.R. Acad.Sci. vol. 205, 1937, pp. 297-298, "Sur le pepillotement en vision laterale."

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flicker
color

Henkes & van der Tweel 1964 (2)

Article by P.L. Walraven & H.J. Leebeek "Phase shift of alternating coloured stimuli" Lange found that sometimes luminance flicker cannot completely be eliminated by adjustment of luminances of two alternating stimuli of different wavelength. The residual flicker can be eliminated by shift of phase of one stimulus with respect to the other. This is thought to be compensation for a phase shift between the responses to these stimuli somewhere in the retinocortical system.

The living brain, by Grey Walters

flicker

The consciousness-expanding experience (i.e. that produced by "hallucinogens" such as LSD) has been produced by flicker at rate of 10-25 flashes per sec. "The rhythmic series of flashes appeared to b e breaking down of some of the physiological barriers between different regions of the brain. This meant that the stimulus of flicker received in the visual projection area of the cortex was breaking bounds, its ripples were flowing into other areas." This overflow of the brain areas, hearing colors, seeing sounds and even odors is a categorical characteristic of the consciousness-expanding drugs. Along with flicker Walters has produced manh of the phenomena associated with consc-exp drugs. Subjects reported "lights like comets ... ultra unearthly colors, mental colors not deep visual ones."

image reinforcement

"Photographic image enhancement through superimposition of multiple images," Final report by H. K. Howell and R. J. Kohler. Itek Labs. Report No. IL-9030-1, AF Contract 33(600)43383, Nov. 15, 1961

Project undertaken to determine whether improvement in information content (i.e. increase in signal-noise ratio) can be effected by printing identical negatives in precise registration. "Identical" refers to relative size & position of photog. image, not to its grain distribution, which is random. Integrating enlarger designed for experimental purposes, precisely superimposing 3 identical negs at 4 and 10X. Resulting "integrated" images subjectively compared with single negs by experienced PIs.

Sub. comparisons ambiguous: observers sometimes preferred single images. Authors conclude that image integration printing can provide significant enhancement in scenes containing areas of low-contrast detail (where addition of noise from grain pattern is relatively severe). For scenes with minumum of low-contrast detail, observers consistently chose single-neg samples. With high-contrast resolving power targets, single negs had better contrast and edge definition, though integrated samples had greater resolution.

Page 65: superimposition technique offers more than simple reduction of random graininess: appears as if superim adds to the info content. Each neg will have (esp. at threshold of res) bits and pieces of detail that the other negs do not possess. Integration of these bits & pieces affords a true gain in the info content of the superimprint. In areas or scenes where this detail is important, superimp technique provides significant image enhnacement. In scenes where little or no imp info located at the threshold of res, the integrated printing tech offers no significant advantage. (Investigators comments: this last conclusion is an egregious truism; anyway it is not clear [illegible] how investigators arrived at "bits and pieces of info" theory. Certainly not proved by experiments made in this project; may be a pious hope of authors.)

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light adapt.

Davson 1962

Troxler phenomenon: progressive dimming & disappearance of illuminated field, the image of which kept steadily on the retina. Generally occurs with artificial stabilization of retinal images. In periphery, esp. at scotopic luminances, readily observed with use of ordinary fixation without artificial stabilization. Even in bright light, when fixation maintained on one point, whole field of vision becomes progressively obscured.

In experiments on dark-adapted eye with 5° field at 20° eccentricity, ceased to see test field 5 to 10 sec after beginning of illumination. Whole visual field then became uniformly dark except for fixation point. When light illuminating test field switched off, field re-appeared momentarily as a dark patch, darker than surrounding "darkness.: This may be due to excitation of off-fibers in optic nerve. Time required for field to become invisible remained constant for field luminances from abs threshold to 1,000 times this. Bleaching of rhodopsin must be negligible at these levels. Phenomenon probably due to processes occurring in nervous connections of retina or in visual pathways, independent of strength of stimulation at receptor level.

Common observation: eye is very poor at determining absolute levels of luminance, whereas it can be very efficient at detecting differences of luminance. A one-sec flash of luminance higher than 3 ft.-L (10 cd/m^2) presented to dark-adapted eye looks brighter than steady field of 15,000 ft-L to which eye has become fully adapted. Complex physiological processes seem to be involved. Subjective brightness experienced during light-adaptation must depend on eye movements, otherwise the adapting field should disappear altogether.

 after images

Davson 1962

Afterimages are the more obvious of the subjective phenomena which occur when eye has been submitted to light stimuli. If close eyes after looking fixedly at light source or illum object, see patch, size & shape of which related to that of source. Few seconds to several minutes, or if very intense primary stim, may last for weeks. If look at uniformly illum surface instead of closing eyes, see afterimages which are darker than the surface ("negative afterimages").

Modes of appearance of afterimages do not obey hard & fast rules. If colored source pos aftérimage may be same color as source, neg afterimage of complementary color. But complicated color effects often observed.

Conditions necessary for physically different stimuli to give indistinguishable afterimages (Brindley 1959). As increase in luminance, smallest detectable difference increaes. Afterimages of flashes of 1.5×10^6 and 1.5×10^7 cd.m^{-2} sec can no longer be distinguished from each other. These two amounts of light are of the right order to correspond to bleaching of the whole of the visual pigment contained in the retinal receptors receiving the flash. Visually equiv amounts of plane-polarized and unpolarized lights produce indistinguishable afterimages. A fixed amt of light, whether delivered during 0.02 sec or distributed over 2 sec, always produces same afterimage, even though subjective effects of stim itself are very different. This seems to suggest that the change responsible for after-images is primarily a photochemical one.

Conditioned afterimages. Subjects made to hear sound when received stimulation. Then after hearing sound alone, without stim, they experienced afterimages. These illusions have something in common with those experienced in abs threshold experiments, when subj sees spurious luminous patch on hearing shutter work, though light is cut off. This latter illusion may be "dark noise" (spontaneous stim of receptor) but may also be due to more complex neurophysiological processes.

Davson 1962 glare illum

Problem of glare studied by Stiles & Crawford (1937) and Crawford (1937) who introduced concept of equivalent veiling luminance. This has proved its usefulness in illuminating engineering, but this does not mean that it necessarily reproduces all effects of glare, esp. when these effects are slight (Stiles, 1954).

Formula for calcul equiv veiling luminance can be used to estimate effect produced by a faint luminous fixation point on the threshold measured using a test field distant from the fixation point. Shows that this effect is progably negligible for a few degrees of angular separation betw field and fixation pt (Pirenne & Denton 1951)

Sci. Am. vol. 209, no. 5 vision physiol
Nov. 1963 p. 54-62
"Visual cortex of the brain" by David H. Hubel

Transformation of retinal image into perception occurs partly inretina but mostly in brain. Ten years ago Kuffler at J. Hopkins discovered that some analysis of visual patterns takes place in nerve cells of retina. Now Hubel and Wiesel at Harvard have mapped visual pathway to sixth step from retina to cerebral cortex. Six types of nerve cells: 3 in retina, one in geniculate body (pair of cell clusters in brain), two in cortex.

Nerve cells or neurons transmit messages as electrochem impulses. In a given fiber all impulses have same amplitude; strength of stimulus reflected in frequency (½ to 100 m/sec). Fiber of nerve cell contadts another, forming junction called synapse. At most synapses impulse releases small amount of a specific substance, which diffuses outward to the membrane of the next cell, where either excites or inhibits. For most synapses, substances that act as transmitters are unknown. Modification & analysis of nerve messages takes place at synapses.

Studies of visual system of cat: record impulses with microelectrodes in incoming & outgoing fibers, infer function of structures.

Receptor cells in retina do not send impulses directly through optic nerve, but connect with retinal cells called bipolar cells. These connect with retinal ganglion cells, which send optic nerve fibers to brain.

Receptor cells may send nerve endings to more than one bipolar; several receptors may converge on one bipolar. Same for synapses betw. bipolar and ganglion cells. Therefore stimulating one receptor influences many bipolar or ganglion cells; or one bipolar or ganglion may be influenced from a number of receptors and hence from a large area of the retina. Any of synapses with a particular cell may be excitatory or inhibitory: stimulation may either increase or decrease cell's "firing rate." May receive several exc. & inh. impulses at once: responds according to net effect of inputs.

cont. next page

Reginal ganglion cells fire at fairly steady rate even in absence of stimulation. Kuffler: resting discharges of g. cells intensified or diminished by light in small circular region of retina (cell's receptive field). Depending where in the field spot of light fell, firing rate increased ('on" response) or decreased ("off" response). Turing light off evoked burst of impulses. Two cell types among ganglions: small circular on-area surrounded by off-area, or the reverse. Effect of light on a given cell vaired according to place where light struck field. E.G., two spots of light on separate parts of an on-area produced more figorous on reponse than either spot alone; if one on on-and the other on off, effects neutralized to very weak on or weak off response. Illuminating entire central on region of an on-center cell evoked max response. Lighting up whole retina diffusesly does not affect retinal ganglion cell so strongly as small circular spot of right size to cover precisely the receptive-field center. Main concern of these cells is contrast in illum between one retinal region and surrounding regions.

Lateral geniculate body has function of increasing disparity between responses to small centered spot and to diffuse light, through greatly enhanced capacity of periphery of geniculate cell's receptive field to cancel effects of center.

Cerebral cortex. Most connections betw cortical cells are perpendicular to surface; arriving impulses probably exert effects quite locally. Moreover, a given area of cortex gets input from a circumscribed area of retina. Therefore a given cortical cell should have a small receptive field. Corticall cells do not have concentric receptive fields: many different types with fields different from retinal & geniculate cells. Two functional groups of cortical cells: "simple" which respond to line stimuli (slits, bars, edges) according to orientation and position on receptive field. "Complex" cortical cells also resp. best to bars, slits, edges, provided that suitably oriented; but not so discriminating as to position of stimulus if properly oriented. Compèex cells respond with sustained firing to moving lines.

cont next page

From preference for specific orientation of stimuli, follows that must be multiplicity of cortical cell types to handle all possible positions. Wiesel & Hubel found large variety of responses but only studied hundreds of individual cells (millions exist).

Simple cortical cells. Receptive field divided into on- and off-areas. Not circularly symmetrical; typically, long narrow on-area adjoined on each side by larger off-areas. Magnitude of response depends on how much either type region covered by stimulating light. Slit of light just filling long on-region produces powerful on-response. Slit in different orientation, much weaker effect; right angles, usually completely ineffective. Pitting of two antagonistic parts of receptive field is carried much farther than it is in the lateral geniculate body. Large spot of light usually evokes no response at all: on- and off-effects precisely balance out.

All arrangements of on- and off-areas have in common that borders are straight parallel. Most efficient stimuli (slits, edges, bars) have straight lines. Optimum orientation for each cell; if other than optimum, less vigorous response, if perpendicular to optimum, usually no response. No evidence that any one orientation more common than others.

Author supposes that simple cell has for input many lateral geniculate cells whose on-centers arranged along a straight line; spot of light anywhere along that line activate some of geniculate cells & lead to activation of cortical cells. Each simple cortical cell has specific duties: takes care of one part of retina, resp. best to one shape of stimulus & to one orientation. For each stimulus -- area of retina, type of line, orientation -- there is a particular set of simple cortical cells that will respond.

cont. next page

Miller, Ratliff, Hartline 1961, cont.

Visual receptor cells in both vertebrates and invertebrates have specially differentiated organelles containing photosensitive pigment. In vertebrates rhodopsin can be seen in outer segments of rods. Absorption spectrum of human rh. corresp. with light sensitivity curve for human vision in dim light, when only rods operative. This is strong evidence that rhodopsin brings about first active event in rod vision: absorption of light by photoreceptor structure. Evidence for similar pigments in outee segments of cones, but hard to isolate and study. Light absorbing part of pigment is relatively simple substance, vitamin A aldehyde, which can exist in various molecular configurations. Absorption of light changes configuration; this leads, by unknown process, to initiation of generator potential of receptor cell and discharge of impulses in optic nerve.

Intensity and duration of illumination (as in photography, shutter speed and lens opening) can be interchanged in human eye exposed to brief flashes of light, to produce constant photochemical effect.

Flicker fusion: light flickering at high rate appears not to be flickering at all. As demonstrated in Limulus, as repetition rate increases, rate of impulse discharge becomes steadier and finally same as response to continuous illumination. Flicker fusion is directly attributable to the generator potential, which becomes smooth at highest repeition rates. (see curves p. 232).

Receptor cells of eye (ear and other organs) are interconnected neurally/ In Limulus, activity of each receptor unit is affected by adjacent activity: frequency of impulses from a unit decreases when light falls on its neighbor. Inhibition probably results from decrease in magnitude of generator potential at site of origin of nerve impulses. When two adjacent units stimulated, each discharges fewer impulses than when one receives same amount of light. Visual effects of inhibitory interaction:

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Miller, Ratliff, Hartline 1961, cont.

Visual effects of inhibitory interaction: differences in neural activity from differently lighted retinal regions are exaggerated, contrast is heightened, and certain significant features of retinal image are accentuated at the expense of fidelity of representation. Limulus ommatidium, with eye masked so that only one unit "observed" pattern, faithfully reproduced form of pattern. Eye unmasked so that all ommatidia observed pattern: frequency increased on bright side of step pattern and decreased near dim side. Net effect: outlines enhanced "border contrast" effect known and used in painting. Similar inhibition in auditory system would sharpen sense of pitch.

In many sense organs, responses can be modified by neural influences exerted back onto them by higher nervous centers. Responses of eye & other complex sense organs are determined by fundamental properties of receptor cells, influences they exert on one another, and control exerted on them by other organs.

Sci. Am. vol. 209 no. 1 — vision physiol
~~July 1963 p. 122-130~~
"Inhibition in visual systems" by Donald Kennedy

In mammalian eyes, some single fibers of the optic nerve discharge impulses when illumination of retina ceases. This signal is mediated by linkage in circuitry of retina. Each fiber of optic nerve collects impulses from a receptive field about 1 mm in diameter, containing several thousand receptor cells. Activity generated in receptor cells converges, through intermediate neurons called bipolar cells, on neurons that form optic nerve. Kinds of connections depend on location in receptive field. In some fields the center, when stimulated by light, produces discharges in optic nerve at "on"; periphery produces discharges only when stimulus is extinguished, at "off."

Interaction of retinal nerve cells blocks on-discharges from some of light receptors by inhibition at synaptic junctions between cells; the generation of off-discharges in response to a shadow results from the release of inhibition in these cells. This interaction plays a vital role in the perception of movement across the visual field, in accentuation of contrast and perception of shape.

Most of article devoted to inhibition in mollusk eyes (ability to see shadows). Mollusks have played distinguished role in development of understanding of relation between photochemistry & visual response.

Photosensitivity may not be unique endowment of highly specialized receptor cells, but a much more basic property. (see urchin, crayfish). Several kinds of excitable cells show "incidental" photosensivity: heart muscle of snails, muscle fibers in pupil of vertebrates, brain cells of some insects, smooth-muscle cells from walls of arterioles in mammalian skin are light sensitive. Ubiquity of this property may guide search for relations between normal pigmented constituents of cells and events that lead to excitation of nerve and muscle membranes.

Sci. Am.
~~Dec. 1956 p. 113~~

"Electrical events in vision" by Lorus J. & Margery J. Milne

Information sent by eye to brain consists of elec impulses arising from eye's absorption of elementary quanta of light. In 19th c. was demonstrated, by making elect connection between outside eyeball and retina, that eye, rather than reaction in brain, was resp. for ratio of response to intensity of stimulus: size of voltage jump is prop. to log of intensity, i.e. to double electrical effect, light energy must increase ten times (Weber-Fechner law, which applies to sensations in general).

Now response of retina to light can be recorded, with electronic amplifiers, as electroretinogram. Since 1925 has been possible to make without removing the eye, i.e., on human subjects.

Adaptation. Eye collects light as length of exp increased, but has threshold of intensity below which no lengthening will make visible. Experiments on eye of horseshoe crab, compound eye each unit of which has a separate nerve fiber toward brain. Rate of impulse varies with dark-adaptation: gets faster as exposure continues, then drops to a lower steady level. Thus dark adaptation and other basic visual properties reside in individual receptor cells.

Cells are most sensitive to yellow-green, least to red, in all vertebrates. Yellow-green is color which penetrates deepest into sea water; sensitivity a heritage ofevolution from aquatic life. Cones are comparatively blind to red, thus can use red for warning lights, instrument panels etc. without losing dark adatation.

Threshold of visual response. Exp. on dark adapted subjects. When saw 50% of flashes, amount of light arriving at eye was 150 quanta of which thought 5-14 actually absorbed by sensitive cells. May have overestimated absorptive quality; threshold may actually be 2-6 quanta. Thus eye approaches ultimate in sensitivity.

OVER

Presumably each absorbed quantum of light energy alters one pigment molecule. If two or three alterations produce a message, why not one? Brain may dismiss one alteration, if not repeated, as insignificant.

Sci. Am. Vol. 211 no. 1
July 1964 p. 24-33

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~~"Control mechanisms of the eye" by Derek H. Fender~~

Article considers eye as servomechanism, or device that controls variable physical quantity by comparing its actual value with adesiredreference value, using difference to adjust the variable.

Cone cells most closely packed in fovea, which is capable of sharpest vision. For close examination, move eyes so that image falls on corresp areas of two foveas. Each of 3 pairs of rotating muscles receives signals proporational to the dipplacement of image from the fovea. Another control system brings eyes to correct angle of convergence; another adjusts focus by changing thickness (focal length) of lens. Acoommodation is not "calculated" from angle of convergence but is achieved by a steady "hunting" mechanism, like focusing a projector lens by hand, which continually shortens and lengthens the focal length until accommodation has been steered to the sharpest focus. Convergence & accommodation mechanisms are separate, but cross-linked: info derived by one is fed to the other, e.g. info on sharpest focus fed across to convergence mechanism.

Another feedback mechanism changes diameter of pupil, linked to accommodative system because increase of focal length requires enlarged pupil to keep brightness of image constant. Another circuit moves eyelikds out of way when look up.

Rest of article devoted to records of eye movements in tracking moving targets. (Eye moves even when staring at a fixed target, in a roughly elliptical area of fixation, tilted because up-down muscles less precise than across muscles.) Two distinct eye motions during fixation: slow drift of visual axis, and sudden change of direction or "flick." Spontaneous movements persist, i.e. eye has a lot of internal "noise." Spontaneous movements must be eliminated in studies of tracking movements. Eye does not travel as far as target, and lags behind it. When movement of target regular, anticipates: an active element which allows it to calculate motion & lock onto it. OVER
Prediction probably a function of cortex, but detection of objects approaching

from side may be built right into retina, because administering of drugs does not suppress velocity signal for targets in periphery of visual field, as does in fovea. Also image-displacement signal (that target is not longer in fovea) is unaffected by drugs & is presumably retinal.

Bipolar cells, amacrine cells, & ganglia in retina seem capable of more than merely passing light signals on to brain: retinas discriminate and filter information in lower animals, & presumably in higher though little known. Microscopic structure of retina is similar to brain: retina is part of brain that became detached in course of evolution. Systems analysis of retinal functions should therefore advance understanding of brain functions.

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color

Davson 1962

Spectrum consists of continuous range of colors & limits given (on p. 224) are only approximate. Different observers give different names to monochromatic lights: e.g. 500 mu may be called blue by one obs and green by anoother. Ends of spectrum not clearly defined; intense radiation of w.l. greater than 700 mu can be seen as deep red light. Light of very long w.l. is not uniform in color. Under suitable conditions UV can be detected down to 315.5 mu.

Eye does not analyze light into components, as ear analyzes sound. Totally different mixtures of monochromatic lights may appear identical. Color percep not an analytical process like the use of a spectroscope. Confusions, or color matches, give much of info from which processes of vision can be inferred.

Dominant wavelength and colorimetric purity of a stimulus together define its chromaticity, i.e. its color quality without reference to brightness. Two colors that when mixed in suitable proportions produce white are termed complementary: red and blue-green, orange and blue, yellow and blue of shorter w.l. Green w.l's have no spectral complementary, but form white with suitably chosen purple lights. If 3 primaries are chosen, say in red, green, and blue portions of spectrum, then any other light can be used to form a match with the 3 primaries.

Discrimination. In practice, experimental work has been largely confined to intensity discrim for lights of similar spectral comp, and chromaticity discrim for lights of equal intensity. Least perceptible diff between 2 lights depends on no. of factors, such as field size, intensity, & criterion adopted for discrim.

Chromaticity discrim. depends on w.l. values. Near limits of spectrum, esp. in deep red, large ~~xxxxx~~ differences in w.l. make no perceptible diff to color of light; near center of vis spectrum, w.l. diff of as little as 1 mu can be detected. Best in blue-green & orange-yellow, with secondary minimum in violet-blue (curve p. 275).

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color vision theory

Davson 1962

Simplest hypothesis which fits facts of color matching is that there are just 3 photosensitive pigments used for color vision contained in three types of retinal cone. The various transformations that may take place in the nervous pathways to the visual cortex are not involved in the (tri-receptor) theory.

Response curves of different types of cone are not reflected in resp curves of all nerve cells in visual pathway. There is "recoding" of receptor response, which may be transmitted in different forms at different stages of the visual pathway. Theories that attempt to give an account of form of response at different stages are known as "zone" or "stage" theories. Such theories cannot be validly based on subjective phenomena alone. Must rely on electrophysiological or histological results. Zone theories at present are based more on intuition than experimental fact.

Opponent-color theory, after Hering, offers only the most nebulous advantages over classical Young theory, and has several grave disadvantages: greater complexity, failure to explain protanopia, and lack of support from electrophysiology. Main reason for its continued existence is confusion of terms.

Discrim., cont. Near ends of spectrum, where w.l. discrim. least accurate, relatively small change in purity (admixture of white light with adju. of luminosity) can be detected, whereas in green, where w.l. discrim. is good, larger addition of white light needed before change in purity detected.

Intensity discrim. In foveal vision, when only cones active, Weber fraction becomes constant for all intensities above a certain level & is independent of color of light. Since all colored lights affect the three mechanisms, diff in intensity, except at very low levels, are detected by whichever mech has the lowest Weber fraction, and the high value of the blue mech does not raise the value of Weber fraction for blue lights.

Low intensities. At very low intensities, color discrim becomes poor & only a few shades can be distinguished. For many colored lights, incl spectral lights, there is no color sensation at all even at intensities well above threshold for perception of light. Interval between threshold of light percep and level at which color can be recognized is photochromatic interval. This interv l must always be defined with ref to the conditions of viewing. When light seen in brief flashes of near-threshold intensity, color recog. is especially bad. Green lights may appear green, white, or red. Red lights sometimes appear colorless, but never any other color. Color confusions attributed to quantum effects. If only a few quanta needed to stim a color mechanism, and if diff in sensitivity betw two mechs is not very great at the wavelength used, the "wrong" mech may by chance be more strongly stim than the "right" one.

Bezold-Brucke effect. At high luminances, spectral lights change apparent color. Red & green lights look more yellowish; blue-gr and violet look blue. On Young theory, a deep red light acts most strongly on red mech, less on green. For very bright lights, red mech approaches saturdation & does not respond so strongly to further increases in intensity. Relative increase in resp. of green mech, which is far from saturation, is accordingly stronger & apparent alteration of color toward yellow. Similar but less striking OVER variation in appar... explicable as diff in gradients of response curves of mechanisms when one of them close to its threshold.

color

Davson 1962

Contrast effects. After adaptation to colored light, white light appears to have hue complementary to adapting light. Successive contrast, due to adaptation of mechs affected by adapting light. Also apparent when colored light viewed after adaptation. Simultaneous contrast: any color placed next to another tends to appear like complementary of adjacent color, thus subjective exaggeration of physical contrast between adj colors. When whole scene ilium by colored light, tendency to ignore the general colorationand "correct" apparent colors of objects. Land experiments depend on combination of "correcting" effect with simultaneous contrast. Photos taken through red & green filters projected on screen using red & white light. General reddening of image largely unnoticed, and parts of screen lit only by white light (corresponding to green & blue objects in original scene) appeared by contrast blue-green.

Simultaneous contrast is explained in the same way as successive contrast -- selective inhibition of one or two of the color mechanisms -- if it is assumed that there can be lateral spread of inhibitory effects across retina. Pirenne (1958) has made psychophysical experiments giving strong evidence of existence of lateral-inhibitory effects in human rod vision.

Sci. Am. vol. 207, no. 5

color

Nov. 1962 p. 120-132

"Visual pigments in man" by W. A. H. Rushton

Reflectivity of backing of retina unchanging; rhodopsin lying in front can be bleached away by strong light. If measure not color but intensity of returning light, can find how much of incident light was absorbed by rhodopsin. Exp. setup uses purple wedge to add the amt of purple which matches that removed by bleaching. Wedge setting for constant photocell output gives rhodopsin density at that moment. Rate of regeneration of bleached rhodopsin follows exponential curve & is 90% complete in 15 minutes.

Field adaptation (quick change of sensitivity to large variable field, such as cloudy sky), not dependent on amt of rhodopsin in rods, or visual pigments in cones, but probably produced entirely by activity of nerve cells, maintaining constant signal strength by exchanging sensitivity for space-time discrimination. Adaptation of bleaching (from light room into dark) is tightly linked to level of rhodopsin. Field adaptation, rapid & unconscious change of gain, makes absolute levels of light intensity hard to judge. In judging brightness we estimate brightness of parts with respect to mean brightness of whole.

Similarly, estimate color of parts of scene in relation to mean wavelength of whole. Color perceptions surprisingly independent of wavelength (Land exp. two superimposed images made on b/w film through different filters appear to contain a large range of color when one is projected by red light and other by white. Eye uses average wavelength of a red-white projection to judge color of parts.

Color matches remain good even in conditions of Land projections. Maxwell showed that all colors could be matched by mixture of red, green, blue primaries, and any 3 colors could be chosen as primaries provided no one of them could be matched by mixture of other two. Trichromaticity of color implies that cones have three pigments.

see next page

Color mixtures, to match, must deceive all 3 cone pigments at same time. Matches depend on wavelength & intensity of light striking 3 pigments, and on absorption spectra of 3 chemicals. Appearances are subj to whole complex of nervous interaction, not only between cone & cone but also between sensation & preconception in mind.

Exp. with red-green blind persons: red-blind (protanope) to measure green-sensitive pigment chlorolabe, and green-blind (deuteranope) for red-sensitive erythrolabe. Spectral absorption of each coincides with sensitivity. Person with normal color vision distinguishes colors in red-orange-yellow-green range because each affects pigments erythrolabe and chlorolabe in different proportions. Blue-sensitive pigment undoubtedly exists, but harder to measure. Fovea is deficient in blue cones as well as rods. Measurements in this area reveal properties of red & green only.

color

Science, vol. 145, no. 3636, Sept. 4, 1964, 1007-1017
"The receptors of human color vision," by George Wald

Determination of spectral senistivities of 3 types of cone must be approached directly: there is no unique theoretical solution: an infinite array of hypothetical trios of spec sens functions, all interconvertible by linear transformations, can satisfy the formal demands of most color-vision measurements.

Exper. on crayfish, which possesses apparatus suitable for color vision: at least two visual pigments segregated in different receptors and poised at about same level of sensitivity. ESensitivity throughout spectrum measured in dark-adapted eye. Then one type of receptor selectively adapted to colored light, and redetermination of visual thresholds throughout spectrum revealsed spec sens of other type of receptor. For example, with eye continuously adapted to red light, spec sens measured was that of the blue-receptor. Response of each type of receptor not at all distorted by such background adaptations. Such invariance with conditions of adaptation is an essentially photochemical criterion, characterizing the activity of a single visual pigments. (This is not necessarily the criterion for isolating a single receptor type, e.g. a cone. A cone containing a mixture of pigments would change in spec sens with color of adapting light.)

This article reports same type of procedure applied to human eye.

When fovea continuously adapted to bright yellow light, spec sens curve is that of blue receptor: high narrow band max at about 435-440. Simultaneous adaptation to wave bands in blue and red (purple light) isolates green receptor: max at about 550 with broad shoulder in blue (an extraneous effect). Adaptation to blue light isolates red receptor. Max about 580-585. Curves for green- and red-receptors overlap widely & may be too much to expect absolute isolations.

Curves corrected to give spect sens at level of cones i.e. eliminate distortion from filtering action of yellow structures, max at 430, 540, 575 mu. Unlike corneal sensitivity curves, corrected curves for two subjects are invariant, as should be if ... of single pigments.

color

Wald 1964 (2)

Ocular and macular absorptions. Spec sensitivity curves, measured in terms of light incident on surface of cornea, are distorted (relative to intrinsic properties of visual pigments) by filtering action of colored structures in eye. These are principally the yellow lens and yellow pigmentation of macula lutea.

Individual differences. Two subjects had relatively high foveal sensitivity in blue, apparently caused by greater than average amt of blue-receptor. Appears to be genetically determined. Another subject with lower than average sensitivity toward violet end of spectrum, probably has denser ocular and macular pigmentation than average. Data for these subjects corrected accordingly.

Beyond 650 mu red-receptor accounts entirely for total senisitivty & hue discrimination ceases. If blue- and green-sensitive cones contained red-sensitive pigment they should still function at long wavelengths. Yellow lights used to isolated spec sens of blue-recep cause so little adaptation in violet that seems unlikely that blue-sensitive cones contain appreciable amts of other pigments. Possibility still remains that red-sensitive cones contain mixtures of pigments.

Blue or violet as primary sensation. This distinction has plagued color vision theory since beginning. Young, Hemlmoltz & author chose violet; common practice at present is to consider blue primary.

Color blindness. discussion p.1015 ff. Color blindness includes not 3 but 4 main types, and indeed two different kinds of "deuteranope." One kind lacks green-sensitive pigment & is literally green-blind; other has all 3 pigments in normal proportions bug red- and green-mechanisms are coupled to form single sensory system. This distinction is fundamental to understanding of subject. If second kind of deuteranope see long w.l.s as yellow as has been reported, may also possess all 3 sensory mechanisms and their disability is a confusion of red- and green-pathways so that both red- and green-sensitive pigments excite both pathways indiscriminately & evoke yellow sensation.

Vision Research, vol. 4, no. 1/2, June 1964, 119-133
"Retinal mechanisms of color vision" by E. F. MacNichol Jr.
(dept. biophysics, Johns Hopkins U., Baltimore)

Entire span of spectral colors can be matched by mixtures of lights of any 3 primary wavelength bands. Problems: uniqueness of yellow sensation, no subjective mixtures of red-green or yellow-blue (but is a bluish green). Many color sensations can be elicited with less than 3 primary colors, esp. when test object is complicated photographic scene (Land).

Analysis of pigment mixtures in solution by partial bleaching technique has not yielded clear indication of different kinds of cone pigments in higher vertebrates, although did distinguish cone pigment iodopsin from rod pigment rhodopsin (Wald 1955). Hypothesis of single receptor acted on by filters ruled out by showing that color matches could be made betw light entering normally through pupil and light entering from behind through sclera.

Simplest way to distinguish betw single- and multireceptor hypotheses is to measure absorption or action spectra of photopigments in situ in sxgg single receptors. Author & others constructed instrument sensitive enough to measure absorption curves of small cones without irreparable distortion due to bleaching. Data for 3 different cones from goldfish retinae: maximum absorption by different receptors in 3 distinct regions of spectrum. This verifies Young's prediction of 3 kinds of receptors for at least one species known to be capable of color discrimination. No significant data on humans or other primates, whose foveal cones smaller & more difficult to measure.

Other type of measurement, direct but ambiguous information: microelectrode technique for recording electrical activity of single neurons. All that can be said at present about mechanism of excitation & conduction in vertebrate photoreceptors is that very little known about it & it presents a real challenge to investigators. Color-related electrical activity has been found (S-potentials) in fish xex retinae. C-responses appear to be signs

SEE NEXT PAGE

C-responses in fish retinae appear to be signs of definite color discrim which is reminiscent of Hering opponent color hypothesis. In mullet, 2 kinds of C-response, a red-green and a blue-yellow opponent pair. In goldfish, units have been found that gave on-responses in long wavelength region and off-resp in short; other units, opposite. Author has tended to regard off-response as post-inhibitory rebound phenomenon which may serve to accentuate termination of inhibitory stimulus. It is clear that in goldfish (at least) wavelength information is carried up optic nerve in form of discharges of axons of a population of ganglion cells which are acted upon by groups of receptors having sensitivities in different parts of spectrum.

At level of S-potential, and later at level of optic nerve fiber discharge, elements that behave consistently with Hering's red-green, blue-yellow, black-white processes. But these elements are in animals which have been shown to have 3 kinds of cones maximally sensitive in 3 spectral regions. Thus a retina may be consistent with Young theory at receptor cell level & with Hering theory at level of optic nerve fibers.

Not certain that same mechanisms operate in primates, but investigations which indicate that retinal mechanisms in fish, monkey & man are not likely to differ very xgx greatly.

vision physiol (color)

The Eye, edited by Hugh Davson. Volume 2: The visual process. New York, London,, Academic Press, 1962. 796 pp.

Wavelength discrimination. Neurophysiology is not concerned with color vision. Its task is to study and analyze mechanisms of wavelength discrimination. Some results may lend themselves to theoretical interpretation in terms of visual experience or behavior reactions to light. Other (results) are parts of a complex organization for transmitting information to the brain, and cannot be so interpreted. Moreover, psychological phanomena of color vision belong to sphere of experience more limited than electrophysiological studies of whole vertebrate kingdom. Even man himself may use only a fraction of whole visual input for building up his world of color. We should be careful not to force psychological interpretations on everything that we can record, knowing as we do that the vestibular control of the gaze is wholly automatic. (p. 577)

Color vision belongs to another conceptual world, that of psychology. Assumption that wavelength discrimination must necessarily lead to "color vision" can only be entertained in the modified version that retinal mechanisms of ~~xxixx~~ wavelength discrimination in some instances also have been made use of to support perception of color. For this reason the neurophysiologist may be interested in considering what his results might mean for understanding of the psychophysical results referring to color vision. (p. 639)

From Hubel and Wiesel's work we are compelled to come to the conclusion that there can be no evoked potentials to diffuse illumination. (Writer thinks their results contain an unknown "x" of selection.) This is strangely reminiscent of situation in which behaviorists conclude from their experiments on "color vision" that the cat can have no discrimination of wavelength. (p. 753)

Light, colour and vision, by Yves Le Grand. Tr. R.W.G. Hunt, J.W.T. Walsh, F.R.W. Hunt. London, Chapman & Hall Ltd., 1957

psychophysics applications

Preface: point of view is essentially that of the physicist. Considers eye as receptor of radiant energy. (Note: author has published, in French, a first volume considering eye as optical instrument, and a third (1956) in which two points of view are brought together. This English translation is the second volume of three.)

No desire to ignore the physiological aspect, which alone can explain the functioning of the retina and the nervous relays, but the accent is definitely a physical one, and the aim is to give to opticians, to those who construct visual apparatus, to illuminating engineers, architects, etc., as much information and as many numerical data as possible concerning response of eye to radiation.

This physical approach, purely experimental and stripped of all theory, forms Section A of the book. Section B contains such elements of anatomy, physiology and psychology as are necessary to understand the various visual theories that have been suggested from time to time.

Science, vol. 128, no. 3329, Oct. 17, 1958, 898-899

color

"Changes in the perceived color of very bright stimuli"
T.N. Cornsweet, H. Fowler, R.G. Rabedeau, R.E. Whalen, D. R. Williams

When very intense stimuli in long wavelength region of visual spectr are viewed continuously, they change in hue from red through yellow to green. Time course of change is related to intensity of stimulus.

Intense yellow stimuli at wavelength of 575 mu (found by Purdy to be "invariant") also changed to green. Green stimuli desaturate but do not turn red.

May be expl by photochem adaptation, if assumed that are at least two photopigments, a red and a green with overlapping absorption spectra, and that rate of regen of green is slightly greater than that of red.

illumination
color

~~J. Opt. Soc. Am. vol. 33, no. 10, Oct. 1942~~ 1943, 555-567

"Some factors and implications of color constancy" By Harry Helson

Colors & forms tend within limits to remain constant in spite of change in illumination and orientation. Problem of color const involves not one but many aspects of vision incl spatial functions of eye. However, nothing like complete preservation of all color dimensions is found under changing conditions: at best only 1 or 2 dimen remain stable while others change. Surface colors approximate various degrees of constancy while colors seen through aperture maintain closer corresp with actual stimulus impinging on retina. But aperture colors are not less subj to influence from the aperture screen than surface colors to surroundings.

Animals below man show constancy tendencies as strong as man. Higher psycho functions therefore not involved.

Limits of compensation. Radical change in composition of illumination from daylight (e.g. spectrally homogeneous light) greatly alters relations betw fundamental dimensions of colors. Breakdown in constancy also occurs when objects viewed at a distance: yellow appears red, then orange, then yellow; violet appears blue, then brown, then black, then violet, with incr. distance. Once limits of comp reached, color changes from common exper are many & baffling.

Visual mechanism behaves as if it had different sensitivities for diff dimensions (Land). Eye is least sensitive to change in general illumination. Wide range of reflectances can yeild black, gray, or white, depending on reflectance of background.

Author regards vis mech as unitary mechanism with extraordinary adaptability of function. Contrast is establ of gradients, not with respect to reflectances of contiguous surfaces, but with resp to adaptation level which tends to be intermediate betw these reflectances. Color compens occurs for diff reasons, but springing from a single source.

Colors also have inherent spatial properties.

OVER

Colors also have inherent spatial properties, insep from contour & boundary effects & just as important for org of the visual field. Color processes not only contribute the matter of visual field, but also determine the way in which the field is organized both bi- and tri-dimensionally. Which is to be regarded as primary, color or space, ks too learly to decide, but evidence points to increasing recognition of importance of color for spatial discriminations.

Cold colors, weak chromas, values near background value, soft edges, dark objects with blue edges, all appear more distant than the reverse. Hard colors (red, yellow, white) have greater organizing power than soft colors (green, blue, black). Hard colors on hard grounds give greater visual acuity than soft colors on soft ground.

Color compensation, by yielding approx color constancy, thus aids in the production of a stable visual world, not only through preserv of color as such but just as much through preserv of spatial organization which is largely due to the color processes of the eye.

color percep

Am. Scientist, vol. 53, no. 3, Sept. 1965, 327-346
"Color names for color space" by Alphonse Chapanis

In comparative judgments of color, normal eye could theoretically distinguish more than 7,000,000 colors (i.e.200 in hue or "wavelength" circle times 450 variations in lightness times 15-165 steps in saturation). In absolute judgments individuals can only name 12-13 colors without appreciable error. Observers are internally consistent, i.e. repeat their own judgments accurately, but diffs betw individuals disconcertingly large, e.g. yellow-ish green to one is bluish-green to another.

Literary & advertising English uses thousands of color names but common English only about 12, with a few modifiers many of which turn out to be synonymous to the average observer. (e.g. vivid, strong, pure and just unmodified "red" mean the same).

Graph p. 341 gives average hue selections for the strong hues, against Munsell hues (note not same.) When authors selected 19 basic color names for experiment, tried to pick names which would fall in Munsell circle at equal intervals. Results show that large region between most of the Munsell greens and all the blue-greens that was not sampled at all by color names. Another large empty space between greenish blue and blue and another between violet and purplish pink. Eye can discriminate between these colors if it wants to ; but we have not found them sufficiently interesting to reward them with distinctive names.

Violet and purple almost completely synonymous to observers, also yellowish green and yellow-green.

Theoretical results: 45 different color names for which selections should not overlap. But 18 per cent of color chips were never selected in experiment; theoeticzl 45 only covers about 82 per cent of Munsell color space. Total no. of different color names probably 52-55. Note that results might have been different if exp. conducted in British English or French (learning important).

Sci. Am. vol. 200, no. 5
May 1959, p. 84-99
"Experiments in color vision," By Edwin H. Land

color percep

Work on natural color images (rather than matching spots of light). Photograph natural scene through two filters that pass different bands; used red and green filters. When illuminate transparencies with practically any pair of wavelengths and superimpose images, obtain colored image. If send longer of two through long-wave (red) photograph and shorter through short-wave photo, obtain most or all of colors in original scene. If reverse process, colors reverse: reds appear as blue-greens etc.

Colors in images arise not from choice of wavelength but from interplay of longer and shorter wavelengths over entire scene.

Width of band makes little difference: one may be as wide as entire visible spectrum (white light). If use red for long record and white for short, colors look about same to color film as they do to the eye. Colors hold fast through very considerable range of light intensities.

Evidently, though eye needs different brightness ratios, distrib. over different parts of the image, to perceive color, ratios that eye is interested in are not simple arithmetic ones. Somehow they involve the entire field of view.

There must be a min. separation between the long-record wavlength and the short. Min. is different for different parts of spectrum, but is astonishingly small. Any pair of wavelengths far enough apart will produce grays & white plus gamut of colors extending well beyond that expected classically from the stimulating wavelengths, incl. nonspectral color sensations such as brown and purple. With some pairs colors maintained over enormous range of brightness; with others, begin to break down with smaller changes.

cont next page

Land 1959 "Experiments in color vision" (2)

Author has formed coordinate system that predicts colors that will be seen in natural images. If put same transparency in both projectors, all points would fall on gray line, since % of avail light same at every point on image for both projectors. Other colors arrange themselves in a systematic way about the 45-degree line. Warm colors above, cool below. Significant scale of color for images is not spectrum arrangement, but runs from warm colors through neutral colors to cool colors. (see graphs p. 89) For every pair of wavelengths that produces full color, position of colors on graph remains same.

Colors in a natural image are determined by relative balance of long & short wavelengths over entire scene, assuming that relationship changes in somewhat random way from point to point. Within broad limits, actual values of wavlengghs makes no difference, nor does over-all avail brightness of each.

Eye is not only adapted to see color in world of light in which it has evolved, but also can respond with a full range of sensation in much more limited worlds. If could find pigments with much narrower response curves, might provide full color in a more restricted world of light -- e.g. a world lighted by wavelengths that pass green filter. A two-color separation photo in a world of any bandwidth is same as a two-color photo in a world of any other bandwidth, provided that a correctly proportioned change in absorption bands of pigments goes along with it.

If eye perceives color by comparing longer & shorter wavelengths, must establish a balance point or fulcrum on one side of which all wavelengths are taken as long & on other side as short. In ordinary sunlight world fulcrum appears to be at 588 mu ("yellow"). When use 588 in one projector, white light in other, image nearly colorless. With length shorter than 588, white serves as longer stimulus; with length longer than 588, white becomes the short record.

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color vision

J. Opt. Soc. Am. vol. 50, no. 3, March 1960, p. 254-268

"Appraisal of Land's work on two-primary color projections" by Deane B. Judd

No new theory is required for the prediction of Land's result that two-primary color projections can produce object-color perceptions of all hues, nor for his result that many choices of pairs of primaries yield substantially the same object-color perceptions. Land's hypothesis that when colors of patches of light making up a scene are restricted to a one-dimensional variation of any sort, the observer usually perceives the objects in that scene as essentially without hue, is new. Several special cases of it are supported by previous work as well as Land's. This hypothesis deserves the serious attention of research workers in object-color perception.

"Classical expectation" of good correlation between color ~~xxg~~ of light patch and perception of color viewed against dark surround applies to aperture mode of perception. This condition is a special case of no great practical interest. Land's discussion implies that ~~xxxx~~ nobody has before noticed that color perceived to belong to patch of light or an object depends on factors other than radiant flux coming from it.

Long established that color perceived to belong to patch of light must be based not only on color of patch but also on those surrounding it and those previously viewed. Author thinks chromatic adaptation bears heavily on Land's results, but possibly other factors are more important. Also discusses object-color constancy. Lack of familiarity with Helmholtz & Helson principles has led Land to conclude erroneously that the facts of color mixture play no role in object-color perception. Memory color: when a familiar object depicted in a scene, color perception of it tends to be changed in direction of color previously perceived to belong to that object.

Land's hypothesis that we need chiefly to consider the info in the long- and middle-wave records is similar to the old disproved hypothesis of the constancy of object-color perceptions regardless of color & amount of illumination.

continued

Judd 1960 "Appraisal of Land's work" (2) — color vision

Color-constancy hypothesis really states that it is hard to fool an observer even though incomplete info is provided for the object-color perception; Land's hypothesis really states that it is hard to fool an observer even though no short-wave information is given him.

Land has discovered that astonishingly satisfactoyy color pictures can be produced by a wide variety of choices of projecting lights by two-primary color projection, and that object-color perceptions are substantially independent of this choice. Has discovered that in evaluating the illuminant color to be discounted, so as to arrive at a valid prediction of object-color perception, only the scene in which the object is observed should be assessed; other scenes within the visual field are irrelevant. "This experiment gives the first premonition that multiple color universes can coexist side by side, or one within another." This is true, and follows from Helmholtz's view that an essential basis of bbject-color perception is discounting of the illuminant color.

Has discovered that in a scene depicting objects shown by two-primary color projection, objects will be perceived as having essentially no hue if amounts C_1 and C_2 of primaries in all pxxp portions of the scene conform to the relation $\log C_1 = a \log_2 C_2 + b$, regardless of values assigned to constants a and b. That is, scene is perceived as chromatic but signals arriving through optic nerve are so processed as to ascribe chromatic character entirely to the illuminant.

Two-primary color processes must fail to yield faithful color rendition to an extent greater than the all too large departures from reality afflicint current three-primary color processes.

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perception (color)

Judd 1960 "Appraisal of Land's work" (3)

Reports of object-color perceptions differ. How can we determine which of a number of interpretations of an ambiguous visual field will be most commonly perceived? The best answer that has been available heretofore is thatascribed to a most gifted student of visual perception, Dr. Adelbert Ames, "What the eye sees is the mind's best guess as to what is out front." Perhaps Land's generalization (about conditions necessary for objects depicted by two-color projection to be perceived as having no hue) will prove to be a reliable guide as to what the mind's best guess will be.

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vision
perception
illumination
color

Sci-Am vol. 208 no. 1
Jan. 1963 p. 107-116

"Perception of neutral colors" by Hans Wallach

Lightness & darkness are propertiés of surfaces (not of light). Amt. of light reflected by a neutral surface depends not only on its reflectance but also on intensity of illuminating light. Light message received from a reflecting surface is thécefore an ambiguous cue to its reflectance or "actual" color. But perceived neutral colors are usually in good agreement with the reflectance of the surface, e.g. a dark gray object tends to look dark gray in all sorts of light. Katz demonstrated "constancy effect" with lighted and shaded gray samples. Effect however is imcomplete.

One variable, the intensity of reflected light, depends on both incident illumination and reflectance of surface. Exp. with dark gray sample against light-colored wall. With room dark, sample looks luminous. As room lightened, luminosity disappears and becomes white; constancy is absent. Further increase in illumination changes to light gray. Light reflected by dark sample is evaluated in terms of general illum on wall; light from projector is ignored. Against a surround of white cardboard, sample looks dark gray; constancy restored and changes in light intensity hardly affect color of sample or surround. In neutral colors, combination of dark gray surface with white surround is resistant to changes in illumination. Surround of any other color fails to produce constancy. Helson suggested that incoming light intensities are evaluated in terms of "weighted average" of stimulation in different parts of retina. Perceived neutral colors depend on ratio between light intensities reflected from adjacent regions -- not on intensity of light as such. Ratio principle operates best when ring and disk are presented against dark background, or when ring fills whole visual field.

Luminosity sensation. Larger of two contrasting areas tends to look luminous; lack of contact between two surfaces increases luminosity. Sp. case of reduced contact: intensity gradient replacing sharp border between areas of different intensities. When intensity OVER difference becomes greater than 4-1, area of higher intensity becomes luminous as well as white; with very large difference it loses all whiteness; e.g., moon by day and by night.

These facts can be explained by considering that stimulation with light gives rise to two perceptual process: one, which causes luminousness, directly dependent on intensity of stimulation & state of adaptation of eye; second, which produces the opaque colors, is an interaction -- area of retina that receives higher intensity of stimu induces sensation of gray or black in neighboring region of lower intensity, with particular color roughly dependent on ratio of intensities.

Exp. demonstrate that lightness of chromatic (as well as neutral) colors depends on relation between intensities of stimulation in different regions. Appearance of disk of chromatic light varies e.g. from yellow to brown, depending on intensity of surrounding ring of white light.

Modes of appearance of chromatic colors. surface colors, opaque colors of objects. Expanse colors (blue sky) in large homogeneous regions, lack density and opaqueness of surface colors. Aperture colors observed when look at through hole in screen at chromatic surface beyond it: surface appears like transparent chromatic film stretched across hole. Raising illumination on screen transofrms "film" into a surface color, like piece of colored paper attached to screen.

Sci. Am. vol. 209, no. 4, Oct 1963 p. 84-93
"Afterimages" by G. S. Brindley

color vision after images

Negative afterimages (seen against white background) presumably due to insensitivity or "fatigue" of some part of the visual system, causedby previous strong stimulation; positive afterimages (seen in darkness) to persistence of stimulatory effects of bright light after it has ceased to shine. Three mechanisms involved in recep of primary colors can be fatigued, and can show persistent excitation, independently of each other. At least part of fatigue resp. for negative afterimages occurs in eye and not in brain (exp. while temporarily blinded due to loss of blood supply).

Bunsen-Roscoe law states that photochemical effects of any two light stimuli are identical if products of strength and time of op. are equal. Eye easily distinguishes between two stimuli, even if this is the case, therefore two flashes must have different effects on nerve cells. Neg. afterimages of two flashes differ for first 15 seconds but after that are indistinguishable. This suggests that late neg afterimage of brief bright stimulus must depend only on its photochemical effects.

In experiments, flashes above 100 units (candelas/m^2 x sec) were discriminated more readily by late afterimages than immediate sensations. Fits hypoth of photochem origin. Total information regarding light intensity capable of being received by pigments of retina is greater than nerve circuitry of visual pathway can transmit instantaneously; but can transmit additional info. later, in form of afterimage.

Flash of 1.5 mil units bleaches about 98% of green- and red-sensitive pigments of cones. Stronger only increased amount to 100%. Any pair of flashes above 1.5 mil units produced indistinguishable afterimages. A single very brief flash, however bright, cannot bleach more than half of a sample of rhodopsin. Human cone pigments posses the same property. Photochem origin of late neg afterimages may be either lack of receptive pigment in bleached cones, or presence of some substance produced by the action of light on the receptive pigment. Lack of pigment cannot explain progressive blurring OVER

Chem. nature of diffusible products. Rod pigment rhodopsin, when activated by light, splits into protein substance opsin, which remains fixed in rods, and retinene 1, which can diffuse out of them. Iodopsin, only receptive cone pigment whose chemistry investigated, consists of retinene 1 combined with a different protein. Cone pigments chlorolabe and erythrolabe may also be made up of retinene 1 and a specific protein and be split by light, yielding r. 1 as diffusible product. But afterimage exp. indicate that different diffusible products are liberated by light acting on chlorolabe and erythrolabe; thus either not r-1 derivatives, or diffusible substances resp. for afterimages are secondary products.

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fatigue

Sci. Am. vol. 196, no. 1
Jan. 1957 p. 52-56
"Pathology of boredom" by Woodburn Heron

Research by Mackworth on radar ops on antisub patrol to find out why sometimes failed to find U-boats. Worked in isolation watching screen continuously. In similar lab situation subjects' efficiency declined in half an hour.

Experiments in a rigidly monotonous environment, from which all patterned or perceptual stimulation removed, to test effects on mental performance. Oral tests performance impaired by isolation in monotonous environment, and poorer than that of control group. Ability to think impaired. Experimental situation induced hallucinations. Halluc have also been reported in exp where subjects exposed for long periods to blank visual fields or flickering light. Halluc began with simple forms & progressed to integrated scenes. Subjects had little control over content. Auditory as well as visual. When subjects emerged after several days of isolation, whole room appeared to be in motion, surfaces appeared curved, and objects changed size and shape. Slow brain waves (typical of sleep) appeared, and frequencies in region of principal brain rhythm slowed down.

Normal functioning of brain depends on continuing arousal reaction generated in the reticular formation, which in turn depends on constant sensory bombardment. Senory stimuli, in addition to specific functions, maintain arousal, but lose power to do so if they are restricted to repeated stimulation in unchanging environment.

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fatigue

Canadian J. of Psych. vol. 8, no. 2, June 1954, 70-76
"Effects of decreased variation in sensory environment" by W. H. Bexton, W. Heron and T.H. Scott

College students used as subjects in this experiment refused to remain under conditions of "homogeneous input" even though paid $20 day.

Canadian J. of Psych. vol. 10, no. 1, March 1956, 13-18
"Visual disturbances after prolonged perceptual isolation" by W. Heron, B.K. Doane and T.H. Scott

Apparent movement of objects, distortion of shapes, intensification of colors. Hallucinations continuedwhen closed eyes or replaced goggles. Effects observed after isolation are not due merely to forgetting of perceptual habits. The Exposing subject to monotonous sensory environment can cause disorganization of brain function similar to, and in some respects as great as, that caused by drugs (such as mescal and lysergic acid) or lesions.

fatigue

Photogram. Eng. vol. 30, no. 6, Nov. 1964, 991-999, 1020
"The practical application of research on visual factors in stereoplotting" by Roland H. Moore and Wendell E. Bryan

1959 study of eye fatigue in stereoplotting in Denver office of USGS, Recommended higher level of ambient light: more comfortable and eliminates visual shocks of abrupt changes in light levels. Optomoetrist serving as consultant devised questionnaire to evaluate indiv opinions of experimental changes. Designed loupe for scribing. Examined eyes, found assorted defects. Recommended continuous optometric service. Recommended elimination of traditional isolated room.

Response of participants to questionnaire varied when given three times. (see graphs)

physiol
percep

Sci. Am. vol. 199, no. 3, Sept. 1958, p. 135-146
"The physiology of imagination" by John C. Eccles

Elec. waves traveling on multilane pathways among the 10 billion cells of cerebral cortex, correspond to the experience of mind.

Article explains transmission of wave fronts from sense organs to cortex, incl. summation of impulses, coossing over, inhibition, etc. These mechanisms explain brain waves made familiar by electroencephalography. In inattentive but waking state predominating wave is 10 per sec "alpha" rhythm. To maintan even this low activity the cortex must be subject to continuous excitation by impulses from lower centers, or lapse into sleep. When brain active, alpha waves give way to fast small irregular waves. Visual experience brings barrage of impulses which disrupts tendency of cortical neurons to settle into phased alpha rhythm. Concentration on problem similarly stirs up heightened neuronal activity over large area of cortex. Alpha waves rel. high voltage: many neurons activated in phase; negligibly small potential of fast waves suggest intense and finely patterned activity.

Each type of sensory receptor activates neurons in narrow vertical columns of cortex. Info from any sense organ must be capable of integration with that from any other. Elec stimuli applied to sensory zones of cortex evoke only chaotic sensations, since excite tends of 000s of neurons directly, regardless of their functional relations.

Memory must be dependent on some enduring change in cortex due to previous activation, such as improvement in efficiency of synapse junctions. May grow in size, or more transmission substance produced. Brain works as patterned activity formed by curving and looping of wavefronts through many neurons with speed deriving from millisecond relay time of indiv neuron.

Tendency to association in imagery: cortex devel more complex & effectively interlocked patterns of neuronal activity involving large fractions of neuron population. OVER

Different image-forming process involved in creative imagination. Prerequisites for creatind activity of subconscious: in neuronal network must be enormous devel of highly complex engrams (perm. impressions left on protoplasm) whose permanency derives from postulated increase of synaptic efficacy. When great wealth of expert knowledge, engrams may occupy greater part of cortex. Some failure in synthesis of engrams or conflict in relationship is neuronal counterpart of a problem to be solved. "Subconscious operation of mind" involves intense & complex interplay of engrams. On repeated activation, tends to be change in their congealed patterns resulting from interaction with other patterns. If an emergent pattern combines & transcends existing patterns, may expect intensification of activity in cortex which brings pattern to conscious attention.

percep
cognition

Sci. Am. vol. 199, no. 3, Sept. 1958, p. 150-166
"The psychology of imagination" by Frank Barron

Average people dislike disorder; creative scientists and artists prefer it, or prefer to impose their own higher order on apparent disorder. Exp. with figure preferences, drawing completion, word association, inkblots. Original scientists had preferences similar to those of artists. In art, preferred works which accented usually unobserved aspects of nature, or attempted radical reconstruction of world of common-sense reality. Behind preference appears a very strong need to achieve the most difficult and far-reaching ordering.

Average subjects disconcertingly ready to abandon evidence of their senses, when contradicted, and bow to consensus. About 25% of subjects not swayed by consensus, but persisted in giving correct answer. (Asch, Sci.Am. Nov. 1955). Independence of judgment is linked to originality & yo preference for asymmetry. Creative people not "psychologically healthy" by ordinary definitions (stability, friendliness, social responsibility). Need another definition. Creative peoples, more at home with complexity and apparent disorder than others, not only respect the irrational in themselves, but court it as the most promising source of novelty in thought. Characteristics:

- Especially observant & value accurate obs
- Often express part truths in order to stress the usually unobserved
- Independent in thought & will suffer pain to testify correctly
- Greater brain capacity; can cope with more ideas at once & make richer synthesis
- More vigorous: large fund of psychic & physical energy
- Universe more complex & lead more complex lives
- More contact with life of unconscious: fantasy, reverie, imagination
- Broad and fl[illegible]

OVER

Writers respon[...] experiments: about 1/5 pointed out intrinsically evil character of psychological research. At its worst it may indeed be destructive, by failing to respect indiv, by presumptuousness of seeking to describe & understand a mystery, by representing encroachment of society. Socially responsible psychs therefore have reason to sleep almost as uneasily as socially responsible physicists.

Sci. Am. vol. 206, no. 1 — after effects

Jan. 1962 p. 44-49

"Aftereffects in perception" by W. C. H. Prentice

Experiments with reversible figures: cannot maintain orientation of outlined cube or octagon w/alternating dark & light sections. Something connected with initial way of seeing the figure becomes satiated. First demonstrated through classical psych methods, hase been correlated with electrochem changes in brain. Sensory stimulus produces current flow through area of cerebral cortex to which stimulus related; current satiates current-carrying capacity of that area, obstructs own passage & diminishes. What experience at a given moment must be in some ways a function of what has experienced in recent past.

W. Kohler, founder of Gestalt school, used reversible figures in study of organization of visual patterns. Gibson (Smith & Cornell) studied normalization of perceived world through learning. Aftereffects -- curving & tilting of straight lines -- could not be explained as normalization. Kohler: same mechanism as "normalization" and reversal of experimental figures.

Figural aftereffects occur in depth as well as plane. Kohler proposed: when impulses set up by a sensory stimulus reach nerve cells in appropriate centers of cerebral cortex, activity of cells must generate direct currents through and around tissue. This must induce a state of polarization at cell interfaces that increases the resistance of the tissue to the flow of current. Conductivity and polarizability of tissue is changed & impulses from later stimulation behave differently.

In visual perception, density of current would be greater in that part of cortex associated with retinal image of figure's edge or contour. As resistance builds up, flow of this current would be displaced to sections of cortex in which tissues offer less resistance: those which correspond to periphery rather than interior of object. If image of a new object now falls on same place on retina, corresp. part of cortex is satiated & will no longer react as it did initially: object appears distorted or displaced.

cont next page

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after effects

Prentice 1962 "Aftereffects in perception" (2)

Simple to demonstrate that brain, not retina, is resp. for devel. of figural aftereffect

Even after Kohler had shown relevance of direct currents to psych findings, psychs and physiols continued to try to explain without recourse to direct currents: proposed complex models of a brain built with insulated pathways. 1946-52 Kohler & associates demonstrated direct currents in human beings. Current generated by moving stimulus. As light moves across field of vision, a wave of potential change precedes it. If moving stimulus stopped, potential difference between two electrodes (one attached to skull over cortex, one grounded) drops to zero immediately.

Direct currents do flow through cortical tissue in respl to stimulation & do build up resistance to their own passage by changing elec properties of cortical tissue. Originally deduced from obs of simple reversible figures. The world one sees at any one time must be determined by what has seen in past. Much of "learning to see" is est. steady levels of satiation so that each new contour presented to eye does not upset operation of visual system. Eyes move often and rapidly over variety of objects: little tendency for satiation to build up in one portion of cortex rather than others (but the reverse if stare at fixed object). Similar phenomena have been found in other senses.

Unwise to stare at fixed contours too long lest subsequent vision be distorted; or to drive along straight highways, where eye continuously stimulated by straight line of edge of road: affecting ability to judge distances on that side.

perception
retinal
rivalry

Sci. Am. vol. 205, no. 3, Sept. 1961, 12-16
letter from Ross H. Day, Brown University

Criticism of Ohwaki (sci. am, Aprl 1961) who reports that well-known geometrical illusions are eliminated or reduced in stereoscopic presentation. This effect is, rather, explained by retinal rivalry, first observed by Panum more than 100 years ago: that stimulus condition in which corresponding retinal points are stimulated by different or "incompatible" patterns. Alternation between patterns falling on each retina.

In figure of oblique and parallel lines, "test element" (parallel lines) in view but "inducing" element (oblique lines) suppressed or inhibited.

Presented various figures stereoscopically and to one eye only. In stereo, lines converging, or circular, across square wholly or partly suppressed; observers saw bright square on field of fragmented lines or circles. Square disappeared less often. Similar effects, with varying degrees of rivalry, with several classical illusions.

For retinal rivalry, not necessary for two parts of figure to be superimposed. Less striking rivalry and suppression when test and inducing contours merely impinge, or are slightly disparate. In stereo, the "inducing" element is eliminated (by rivalry" from the pattern; therefore the illusory effect not observed.

perception

Canadian J. of Psych, vol. 14, no. 2, 67-77, 1960
"Visual perception approached by the method of stabilized images,"
by R. M. Pritchard, W. Heron and D. O. Hebb

Stabilizing an image (by projecting from contact lens), thus eliminating involuntary eye movements, leads rapidly to disappearance of image, followed by interimittent reappearance. Length of time line is visible is function ofthickness.

Meaninful diagram visible longer than meaningless. Straight line acts as unit. Angles and corners not perceptual elements, as is stated elsewhere.

Evidence of functional meaning of "good" figure per Gestalt psych; of functioning of whole as perceptual entity; of groups as entities; of similarity & contiguity as determinants of grouping; marked field effects.

But action of parts independent of whole tends to predominate over the whole in way that never occurs in normal vision. Conclusion: the "wholes" in question are simpler ones than usually discussed in Gestalt psych: straight lines or short segments of curves. More complex wholes are synetheses of simpler ones, though also function as genuine single entities.

percept
eye movement

J. Opt. Soc. Am., vol. 49, no. 8, Aug. 1959, 741-745

"Visual effects of varying the extent of compensation for eye movements,"
by Lorrin A. Riggs and S. Ulker Tulunay

Studies of visual effects of essentially motionless image on retina. Devised a method, using contact lenses, whereby a retinal image did not change its position despite eye movements: image reflected on screen, retinal image moved through exactly same angular distance as eye. Elimination of image motion caused disappearance of target, by a progressive washing out of contours. Contours could be restored by blinking or effecting large motion of eye, thus causing large variations of luminance with respect to retinal receptors. Image can be restored to vision after disappearnce if image motion introduced in amt of 1 min of arc. (During attempted steady fixation, eye normally wanders over about 10 min)

Retinal image of a straight line is imaged as blurred band of light whose width determined by diffraction, optical aberrations, & scatter. Under most favorable conditions, width of band is not less than about 38 sec of arc. This means that any one cone receptor is not affected by full difference in luminance across a border until a motion of 38 sec or more has occurred. With 10% error of stabilization this would require an eye movement of 6.3 min of arc, somewhat larger than typical rapid saccades or slow waves that are found during steady fixation.

Hartline has shown that a single ganglion cell axon in a vertebrate retina can be stimulated by moving image of a line across retina. Very small movements ineffective, but larger ones, that rep motions of 4 cone diameters in visual field, arouse vigorous responses. These results are for off and on-off types of fibers only; some fibers are capable of responding during steady illumination. Nevertheless, maintenance of vision probably dependent on responses of those retinal units that are specialized for detecting transient variations of the retinal image

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perception
vision
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Sci. Am. vol. 204, no. 6, June 1961
~~June 1961 p. 72-78~~

"Stabilized images on the retina" by Roy M. Pritchard

Movements of eye when "fixated" on a stationary object: slow drift away from center of fovea; this terminates in a flick which brings image back toward center; in addition, a tremor, frequency up to 150 cps and amplitude about ½ frequency of a single cone receptor. This motion plays significant role in sensory functions: when an image stabilized, its soon fades and disappears. Regenerates after time and becomes partly or completely visible; over prolonged periods, alternately fades and regenerates.

This alternation is related to character and content of image. Evidence from exp. at McGill U. suggests that pattern perception must be explained by reconciling "cell assembly" (learning is necessary to perceive pattern, combining separate neural impressions in brain) and Gestalt (perception is innately determined, perceived directly as whole without synthesis of parts) theories. (cf Fantz 1961)

Image stabilized by attaching target to eyeball: contact lens, on which mounted small optical projector, set on cornea and focused. After few seconds, image disappears progressively, leaving structureless gray field. Simplex figures such as lines vanish rapidly and repppear as complete images. Complex images may vanish in fragments, parts fading independently. Time of persistence of image is function of eomplexity.

Cell-assembly approach explains independence of parts as "perceptual elements" established by experience. Meaningful elements remain visible longer than unorganized ones. Gestalt: part independence also appears with meaningless figures and can be explained by holistic perception. Contiguity and similarity strongly determine functioning of groups of images. Stimulus excites perceptual response that goes beyond retinal region of actual stimulation. Most stabilized figures are seen as three-dimensional. Color disappears quickly from stabilized images, leaving colorless field of different brightnesses. Supports theory that perception of hue is maintained by continuous changes in luminosity of radiation falling on receptor.

OVER

In other words, movement of edges of a patch of color across the retina, produced by normal eye movements, would be necessary for continuous perception of color. Investigators are studying ~~xmmpx~~ amplitude, frequency and form of movement necessary to sustain or regenerate a particular color.

eye movements

Davson 1962

Eye movements are necessary to counteract fading (which takes place when image stabilized on retina) and the on/off play that is bound to take place around contours or any other boundaries between different levels of brightness must be formidable, to judge from the rapidity with which even the cold-blooded frog eye responds when a pencil is drawn through a narrow light beam focused on it.

With moderately good stabilization, colors become desaturated and perception of form is impaired. With good stabilization the target becomes gray and then dark. Normal vision can be restored by introducing controlled movements or using flickering light.

All acts of visual discrimination are based on an interpretation of a dynamic on/off pattern, an unstable image rather than a stopped one.

perception

Sci. Am. vol. 212, no. 4, Apr. 1965, 46-54
"Attitude and pupil size" by Eckhard H. Hess

When shown interesting or attractive pictures, pupils of eyes dilate. Response is a measure of interest, emotion, thought processes & attitudes. Even overcomes the physical response to light, i.e. when slide shown, every part of screen brighter than before, so response ought to be negative: eye should constrict slightly. Instead got positive responses that would have been expected. Constriction occurred only for stimuli that person might find unappealing.

Some stimuli, e.g. pictures of battlefields, have strong shock content and cause initial dilation; with repeated presentation, shift to constriction. Time interval makes little difference.

Pupils dilate during mental activity, e.g. arithmetic problem solving. Return to normal when subject gives answer to problem. (not when solves)

psych
percep

Sci. Am. vol. 212, no. 2, Feb. 1965, 38-48

"Texture and visual perception" by Bela Julesz

Studied extent to which one can perceive differences in visual patternswhen all familiar cues removed, in order to dissociate primitive mechanisms of perception from complex ones that depend on learned habits of recognition. Questions: can two unfamiliar objects connected in space be distinguished from differences in susface texture? can two unfamiliar objects with identical surface texture be distinguished from separation in space?

Role of texture in discrimination. Random-dot patterns with different properties were generated side by side. Might expect that texture discrimination governed by variations in statistical properties of patterns. (Why??) Exp. showed that simple statistical measurements of brightness not adequate to describe perceptual performance. Discrim. of texture involves a kind of preprocessing: neighboring points with similar brightness values are perceived asforming clusters of lines. "Connectivity detection." Texture discrim. is really based on relatively simple statistics of these clusters.

Spontaneous discrim. occurs even though two fields have same average tonal quality, because granularity of fields is different. Nonspontaneous discrim.: two half fields of same apparent texture and granularity, but one half forms English words, other random sequences of letters.

Visual system incorporates a slicer mechanism that separates adjacent brightness levels into two broad categories ofdark and light. Level of slicingcan be adjusted, but it is impossible to form clusters by shifting our attention to dots that are not adjacent in brightness. Same connectivity rules hold for patterns composed of dots of different colors adjusted to have the same subjective brightness. Example: red-yellow field easily dist. from a blue-green, but red-green harder to dist. from blue-yellow. Dots of nonadjacent hue (red-green, blue-yellow) do not form clusters.

cont next page

perception
stereo

Julesz 1965, "Texture & visual discrimination" (2)

Clustering of adjacent brightness levels or hues is important preprocessing mechanism. When presented with complex patterns, visual system does not perform statistical analysis but detects clusters and evaluates only a few of their simpler properties. Objects can be distinguished by differences in surface texture alone, even if spatially connected and cannot be recognized. Texture discrim. depends on properties of clusters. Cluster detection seems to be primitive & general process (frogs & cats). Slit detector in cat's visual system is case of connectivity detection (????).

Spatial separation of objects. Computer generated random-dot patterns identical except for a central area with parallax displacement. Could be detected in stereo even when (1) one image blurred, (2) one image reduced 10%, (3) one image noisy. See illustr. page 44. (But depth perception of these imperfect pairs is also imperfect!) Stereo picture is devoid of all familiarity and depth cues. This disproves a long-standing hypothesis of depth perception, which assumes that the slightly different images projected ontothe two retinas are first monocularly recognized and then matched. Monocular recog. of shapes is unnecessary for depth perception. Depth phenomena can be perceived in very short interval (a few milliseconds presentation time). Depth perception must therefore occur at some point in central nervous system after projected images have been fed into a common neural pathway. But when long presentation time, convergence motions of eye do influence depth perception. Processing in nervous system that gives rise to depth perception is now more mystery than ever. Random-dot stereo pairs actually easier to perceive in depth than images of real objects. (?)

According to Gestalt psych stereo occurs as each eye works up complex of stimuli into a Gestalt; difference between two G's causes impression of depth. With random-dot images no Gestalten can be worked up. In image of raised square with fuzzy edges, black-and-white elements along border have equal probability of being perceived as part of raised panel or surround. Per G. psych. square (having good G.) would be perceived.

percep
stereo

Julesz 1965, "Texture and visual discrimination" (3)

Subliminal perception of depth. Second pair flashed onto screen immediately after first pair (original purpose, to erase afterimage). First has panel unmistakably in front of or behind surround; second, panel ambiguous, may be either. With short interval between,subjects did not notice first pair, which, however, influenced perception of second. When presentation time of first pair long enough, ambiguous panel in second seemed at same depth as in first. (40 milliseconds, the min. perception time for stereopsis). All this processing must take place in central nervous system, because times are too short for eye motion.

Texture discrim. and depth perception operate under simpler conditions than has been thought, since they do not require the recognition of form. It is therefore feasible to design a machine for automatic production of contour maps according to info in stereo aerial photos. Connectivity detection is basic to both visual tasks, and is more primitive process than form recognition.

psych
percep

Julesz 1965, "Texture and visual discrimination"

Investigator's comments. At least a decade ago, photo interpreters were perfectly aware that form recognition is not required for stereo. For example, the tests of stereo perception published by Moessner required perception of apparent height of individual dots (not even random patterns of dots) above, on, or below the datum plane; and recognition of apparently raised letters in a random array which formed a sentence when perceived in stereo. I think only psychologists were under the delusion that form recognition was important for stereo fusion, and that because they had misapplied Gestalt theory in a rather naive way. Author's "connectivity detection" is likewise misapplied to the orientation preferences of the cortical cells of cats (see Hubel 1963).

The examples of imperfect stereo pairs given in this article demonstrate to the investigator that perception of such pairs is also imperfect. The example with one blurred image causes an interesting case of retinal rivalry, in which blurred and sharp parts of the image are seen in distinct pattern over the field. The out-of-scale and noisy images can be perceived in stereo intermittently: the corners of the square drop off and reappear, and usually only one edge can be seen in good steady stereo at one time. Conditions like these, or viewers which present conditions like these (e.g. binocular "stereo" of different sets of photography, which differ in scale, orientation, and sharpness) could hardly be recommended for photo interpretation. (I wonder how his subjects reported their stereo impressions of these examples. We all know that people sometimes rave about stereo when in fact they see none, and that it takes some experience to notice and criticize the quality of the stereo that one does see.)

The author has spent a great deal of experimental time belaboring the obvious, and making questionable connections between his coined terms and the controlled work of physiologists on neural pathways in anesthetized animals.

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vision
~~physiol~~
perception

Sci. Am.
May 1961 p. 66
"Origin of form perception" by R. L. Fantz

As well as seeing light, color, and movement, young infants respond selectively to shape, pattern, size, and solidity. This behavior had already been demonstrated in chicks, which peck selectively at shapes resembling grain, and in herring gulls, which prefer shapes resembling parent's bill. Infants look consistently at some forms rather than others, so must be able to perceive form. More complex forms draw greater attention. Not result of learning process, since appears at all ages. Acuity of vision is poor at birth & improves (width of stripes that could be distinguished).

Problem of learning: monkeys kept in dark from birth had to learn to see. Complex interaction of innate ability, maturation, and learning in development of visual behavior. There is a critical age for devel. of given visual response, when visual, mental, and motor capacities are ready to be used. If response is not "imprinted" at critical age for lack of stimulus, development proceeds abnormally. At later age, experience & training are needed to respond to stimulus.

Infants prefer face patterns: there is an unlearned primitive meaning in form perception. Prefer solid objects. Interest in pattern is greater than in color and brightness. Pattern is better guide to identification under diverse conditions. Specific type of pattern, surface texture, provides orientation in space.

Interest in kinds of form that will later aid in object recognition, social responsiveness & spatial orientation demonstrates innate knowledge of environment.

Sci. Am. vol 204 no. 3
March 1961 p. 138-148
"Shadows & depth perception" by Eckhard H. Hess

Modern psychologists, as well as early investigators, tend to take view that learning and experience are dominant in determining response to cues of light and shadow. Some aspects of this faculty may depend on innate mechanisms.

Human subjects interpreted image as in relief when presented "right side up", and light as xxxxxx coinciding with angle at which picture tilted. If picture in positions beyond 90 degrees left or right of upright, most saw it in intaglio but light source 180 degrees from angle of tilt of picture. Assumed that source of light above horizon, and impression of intaglio resulted from continuing assumption.

Experiments with chicks gave evidence that response to cue of light and shadow is product of learning and experience. However, control chicks responded to cues sooner than experimental chicks: this leaves some ground for arguing an innate preference for toplighted objects.

Some other types of visual depth perception, e.g. motion parallax, seem to require innate mechanisms.

Sci. Am. vol. xx 198, no. 1 — perception, cognition
Jan. 1958 p. 77-82
"Experiments in discrimination" by N. Gattman & H. I. Kalish

Stimulus generalization: a learned response to specific stimulus carries over to whole class of similar stimuli. Hovland & others have shown that there is a graded generalization of response to sounds and to visual stimuli, declining with changes in pitch or in brightness or size of object.

Pigeons trained to peck at light of given wavelength, responded in regular pattern to different wavelengths, according to distance from stimulus used in training. Curve of response crossed color boundaries without abrupt drops. Birds recognize wavelengths entirely without reference to color (? - non seq). Generalization and discrimination may therefore not be simple opposites, as commonly supposed. (?) Training in discrimation (between two wavelengths) enhanced response to new range; i.e., shifted peak response away from the negative stimulus. As response to conditioned stimulus increased, resp. to associated stimuli increased in same ratio.

Stresses may heightenxx generalization & extend its range, i.e. show exaggerated reactions to stimuli which ordinarily would evoke no response. In extreme case would react indiscriminately to virtually all stimuli in environxxment.

Sci. Am. vol. 210 no. 6
June 1964 p. 94 -102
"Vusual search" by Ulric Neissen

vision
search

Perceptual analysis seems to be carried out by many separate mechanisms arranged in a hierarchy, the more complex receiving as their input the information that has been assimilated & digested by more elmentary ones. Experiments with visual search at the boundary between perception & thought: finding letters, words, numbers in lists. Some combination of feature-detectors is presumably sufficient to penetrate the nervous system far enough to stimulate activity in some subsystem sensitive to the letter that is sought; activity suppressed for all other characters. Subject does not identify the letters not sought, and cannot remember them when changed.

Multiple search does not take more time, so extra infommation must be flowing in parallel rather than in increased depth. Many processes can be carried out together (8n contrast to intellectual thought, in which lose efficiency) because of relatively low level of the cognitive analysis involved in scanning. Achievements of newspaper clipping readers, who scan for a thousand or so targets at once, confirm that speed of search is independent of the no. of different targets that can terminate it successfully. Cognitive operations involved are more than simply a search for component letters ~~xxxxxxx~~ (of a word sought) and less than full appreciation of the meaning of each word scanned.

Subjects in tests began at different degrees of efficiency but in letter-seeking tests leveled off at a common rate of about 10 lines per second. With practice multiple targets could be found just as quickly as a single target. Where the problem is to find a line that does not contain a given letter, only about 4-5 lines per second.

Context of garget is important, e.g. letter Z is quickly found among round letters but only slowly among angular ones.

Process of learning efficiency is variable & not considered in this article.

perception

Sci. Am.
July 1950
"Arrested vision" by Austin H. Riesen

Depriving animals of patterned visual stimuli for period after birth impairs their later visual performance, especially in form perception. Even innate responses are affected.

cognition

Sci. Am. vol. 212, no. 3, March 1965, 42-50
"Learning in the octopus" by Brian B. Boycott

Karl Lashley studied cerebral cortex of mammals. Concluded that in org of a memory, involvement of specific groups of nerve cells is not as imp as the total no of nerve cells avail for organization. At least in the octopus's vertical lobe & mammalian cerebral cortex, memory is everywhere and nowhere in particular (relation betw amount of vertical lobe left intact & accuracy of learned response).

Memory must consist not only of representation of learned situation, but also a mechanism that enables the rep to persist. In octopus, exp demonstrated a short-term memory which, by continuing activity between intervals of training, leads to long-term change in brain. Epileptic patients with temporal lobes removed: man's cerebral cortex incorporates a long-term memory system but hippocampal system (affected by surgery) is essential to establishment of new long-term memories. Hipp. system may have function of linking two memory mechanisms --"whatever that may mean."

Evolution of memory: Young proposes that chemotactile & visual centers devel from a primitive taste-and-bite reflex mech. More indirect relation betw change in environ and response. Signal systems of longer duration than provided by simple reflex had to evolve: learning had to become possible so that animal could assess significance of distant environ change.

Lashley (Harvard): "I sometimes feel, in reviewing the evidence on the localization of the memory trace, that the necessary conclusion is that learning is just not possible."

Sci. Am. vol. 198, March 1958 p. 94-102
"Helmholtz" by A. C. Crombie

H. was trained in medicine & was physicist, physiologist, and philospher. Gave law of conservation of energy its broadest & most definitive formulation. Study of optics; invented ophthalmosocope; physics of sound & theory of ~~xxxxxxxxxx~~ vowel tones; relations of optics to painting.

Theory of knowledge. "sensations are, as regards their quality, only signs of external objects, and in no sense images of any degree of resemblance." Only connection betw sensation & object is that both appear simultaneously. Sensations are "signs that we have learned to decipher ... a language given us with our organization by which external objects discourse to us."

Nature of elec and magnetic forces. Three rival theories of electromag forces existed. H. showed that all 3 were sp cases of a more general math theory & devised tests to determine which sp theory to be adopted. Left with that of Faraday & Maxwell that elec & mag forces are propagaged through an all-pervading ether. Math interp of Maxwell's theory that light is another form of electromag wave stimulated Hertz to make exp in electromag radiation, which est theory of light & made radio communication possible.

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Human behavior: an inventory of scientific findings,
by Bernard Berelson and Gary A. Steiner. Harcourt, Brace, & World, 1964.
(reviewed by Jules Henry in Sci.Am. July 1964)

Publ. of this book provides what is needed to consolidate a general theory of intellectual failure in the behavioral sciences. Most significant factors in failure: (1) inability to dist. truism from discovery; (2) insensitivity to platitude; (3) insensitivity to tautology; (4) confusion of causal sequence (5) misperception of variables (6) delusion of precision, or imagining instruments to be sharper than they are and throwing away large but imp. minor percentages (7) issue-avoidance (8) drawing of simple-minded parallels (9) multiparaphrasis or repeated quotation & misquotation (10) failure to observe law of homologous extrapolation, e.g. extrapolating laws of rat or pigeon learning to man, deriving proofs of human behavior from exp with lower animals. (11) lack of existential concept of man. All above errors of judgment derive from fact that authors avoid human existence.

Quotes from book 1 p. before end:"Indeed as one reviews this set of findings, ~~xxx~~ he (sic) may well be impressed by another omission perhaps more striking still. As one lives life or observes it around him (or within himself) or finds it in a work of art, he seesa richness that somehow has fallen through the ~~xx~~ present screen of the behavioral sciences. This book, for example, has rather little to say about central human concerns: nobility, moral courage, ethical torments, the delicate relation of father & son or of the marriage state, life's way of corrupting innocence, the rightness and wrongness of acts, evil, happiness, love and hate, death, even sex."

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Vision and value, G. Kepes, ed. Vol. I,
Education of Vision. George Braziller, 1965. 233 pp.

In vol. 1 of this 3-vol. series, psychologists lead off with analyses of fundamental characteristics of seeing. Arnheim attempts to establish "visual thinking" as an operation valid in its own right, not an instrument [illegible] Holton, a physicist, discusses vision as implement for understanding ~~xxxxx~~ physical world.

Amer. Scholar, vol. 34, no. 2, spring 1965, p. 179-198

"Humanistic biology," by Rene Dubos

Success of comparative biology may have retarded growth of knowledge about man himself. All living forms have many characteristics in common; biols and med scientists tend to focus investigation on organisms simpler & easier to manipulate in lab (e.g., horseshoe crab). This tendendy is based on widespread (but unproved) assumption that understanding of man will eventually emerge from detailed knowledge of elementary structures & functions that occur in all living things. A deplorable consequence of this attitude is the common belief that the only fields of biology that deserve to be called "fundamental" are those that deal with the simplest manifestations of life.

Failure to account at present for many cognitive & emotional aspects of human life has origin in fact that words "mind" and "emotion" as commonly used cannot possibly refer to attributes located in fragments isolated from the body or associated with special chemical reactions. Instead, they denote activities of integrated organism responding as a whole to external or internal stimuli.

Higher the position of an animal on the phylogenetic ladder, the more unpredictable its behavior with regard to environmental stimuli. Words "reaction" and "response" symbolize wide interplay betw man and environment. At one extreme man appears as ordinary (though complex) physiochemical machine, reacting with env forces according to the same laws that govern inanimate matter. At other, man seems rarely a passive component in the reacting system; characteristic aspect of behavior is that responds actively and creatively. VCan shut out or modify some of stimuli or use their effects to his selected ends.

All social stimuli -- crowding, isOlation, challenge have effects that originate in evolutionary past (e.g. fright-flight) and tend to imitate kind of response that was then favorable for survival, even when response no longer suitable to conditions of modern world.

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Dubos 1965 "Humanistic biology" (2)

Ancient biol traits explain such phenomena as mob psych aberrations, physical symptoms of anger, urge to control property & dominate, aesthetic characteristics. Animal behavior also provides prototypes of these (territoriality, dominance, asethetic preferences)

These biol traits have been grossly neglected by biologists. This neglect is the result of the historical accident that scientific biol has been identified from its beginning with concept that body is complex but otherwise ordinary machine & that detailed analysis of its elementary structures & energy mechanisms is the only valid approach to the understanding of the living organism. This attitude has discouraged the scientific study of biol problems that do not lend themselves to the reductionist analytical methods now in vogue among experimental scientists.

Man's sense of discreteness is one of most cherished & pronounced characteristics. Failure of theoretical biol to emphasize uniqueness of individuals contributes to its lack of influence on the humanities.

Environmental influences contribute to shaping of personality by interfering with acquisition of new experiences: aptitude to apprehend external world becomes saturated as mind & senses are conditioned by repeated experiences. Environ influences also determine certain patterns of response which can affect all manifestations of behavior E.g., endless variety of conditioned responses, from dog salivation to Proustian assoc. with past.

Activity of neural processes in brain is continuous. Stimuli give form to the acitivity rather than arouse inactive tissue. These findings, plus knowledge that sensory deprivation causes transient disintegration of personality, suggest that ways may be found to prevent or retard the setting of personality

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Dubos 1965 "Humanistic biology" (3)

Systematic effort should be made to describe & analyzes pattern of responses that man makes to all the stimuli that impinge on him. Such knowledge could be acquired if biols devoted to study of living experience as much skill & energy as have devoted to description of body machine. Animal kingdom provides experimental models for many of interesting problems of human life. Biols have been immensely successful in describing elementary structures & processes of body, but have neglected study of living experience. Commonly stated that biol has become "too scientific" to concern self with problems of humanness. In author's opinion difficulty is that biol is not scientific enough. One of responsibilities of science is development of objective methods for describing all aspects of reality.

 "human factors"

Chapanis, Alphonse
(author of article on color naming in Amer. Scientist Sept. 1965)

Ph.D. Yale 1943. Air Force 1943-46.
Johns Hopkins University - 1956, Prof. of Psych. and Industrial Engineering.
Fellow of Amer. Psych. Associ. - award 1963 for outstanding contributions in the field of eng psychology and was electxed Pres. of Human Factors Society for 1963-64.