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FINAL REPORT NO. 226
June 30, 1966

VISUAL FACTORS RELATING TO IMAGE INTERPRETATION

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TABLE OF CONTENTS

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1. INTRODUCTION

STAT This is the final report on [redacted] Project No. 9277, "A Literature Search of Visual Processes Relating to Photointerpretation." The objective of this project has been to screen existing literature and research data on vision and perception for significant factors applicable to the task of the image interpreter. Ideally, these factors can then be utilized in design considerations for interpretation equipment or working environment.

The encyclopedic nature of the topic under investigation has necessitated a rather general approach in "feeling out" those specific subjects or sources that appear most germane. During the course of the project, the sponsor's program monitor has defined a number of specific topics of particular or current interest to be investigated. Project reporting, to a large degree, reflects these indicated fields of interest. Because of the broad and varied implications of the overall subject of "vision research", and the admitted difficulty of extrapolating purely experimental or isolated results to the complex function of image interpretation, we would recommend that any future effort of this nature concentrate on specific aspects of vision that can be related to individual tasks of the image interpreter. A primary difficulty of a shotgun-type investigation lies in the lack of a universally agreed-upon definition of "image interpretation." Additionally, the various academic or technical disciplines concerned with research on visual processes often take widely differing or even conflicting approaches to the subject.

Principal investigator for the project initially was [redacted] STAT
STAT [redacted] On her departure from [redacted] became principal investigator. STAT

STAT In April, 1966, [redacted] attended the SPIE Symposium, "The Human in the Photo-Optical System." Abstracts and comments on those papers are presented in Appendix A.

Appendix B is an annotated bibliography of sources and abstracts, arranged by subtopics. Much of the abstracted material presented is in the form of working notes compiled during the investigations. As such, it represents an attempt to grasp and become educated in the terminology and theories of vision. It should not be regarded as a comprehensive tutorial on the subject in place of a good sound course in physiological optics.

Previous reports under this project include:

(1) Letter report, September 24, 1965 - included preliminary discussion of wavelength discrimination.

(2) Letter report, October 28, 1965 - included preliminary discussion of visual acuity and visual threshold.

(3) Quarterly report, December 15, 1965 - March 15, 1966 entitled "Human Factors Aspects of Photointerpretation."

2. GENERAL

Vision is a physiological process which takes place through complex interaction of retinal receptors in the eye, nerve connectors, and brain. A great deal of impressive work has been done to explain this process, and in the past couple of years the physiological mechanisms of vision have become quite definitely known.

The processes of vision are rather far removed from the experience of the PI or other worker doing a visual task. What does apply to the experience of the worker is not the physiology of vision, but the psychophysics of perception. This is a specialty in which subjective data on perception -- what he sees, thinks that he sees, or says that he sees when confronted with a stimulus -- are experimentally treated. "Vision" and "perception" are often loosely and interchangeably used, and this loose usage need not bother us particularly, once we ourselves have a clear idea that there is a difference.

Libraries full of fine work have been written on the photochemistry of the retina, the visual neural pathway, and so forth. This work is one example of the impressive success of comparative biology with reductionist and analytical methods. Biologists have tended to focus investigation on organisms which are simpler and easier to manipulate in the laboratory than man, not only because this is more socially acceptable, but also because of a widespread assumption that understanding of man will eventually emerge from detailed knowledge of the structures that occur in other living forms (Dubos, 1965). For example, a great deal of physiological experimentation has been done on the visual mechanisms of clams, horseshoe crabs, cats, and rabbits. This work is valuable and interesting in itself. Among other things it has confirmed the classical theory to tri-receptor wavelength discrimination in vertebrate eyes (MacNichol, 1964). However, neurophysiologists insist that we should not force psychological interpretations on the physical facts that we can record. For example, neurophysiology is not concerned with color perception, but with mechanisms of wavelength discrimination. Some facts about these mechanisms may lend themselves to interpretation in terms of visual experience; others are fractional parts of a complex nervous organization, and cannot be so interpreted (Davson and others, 1962). Even without these professional warnings, common sense should tell us that the visual response of an anesthetized cat is not directly applicable to the perceptions of the photo interpreter.

In spite of the progress which has been made in explaining the photochemistry of wavelength discrimination, subjective color perception remains essentially a mystery. It is not a simple response to wavelength, but depends heavily on the "field" or color world to which the person is subjected. The eye has remarkable "constancy" or tendency to maintain colors (and shades of gray) in various kinds of illumination. Land (1959) found that this constancy effect is far more extensive than had been supposed, and that the eye can in fact create normal colors in a color world much more restricted than the ordinary daylight world. Colors also possess intrinsic spatial properties (Nelsen 1943); intense long-wavelength colors change in hue when viewed continuously, from red through yellow to green (Cornsweet and others, 1958), probably owing to differential rates of bleaching of the pigments. In addition, colors have decided emotional effects, as indicated in studies revealing variations in response to colors as a function of ethnic or national background.

The visual tasks and functions of the image interpreter can often add up to a weird combination of undesirable conditions. Visual and muscular discomfort are imposed, in some degree ranging from minor stress to outright abuse, by all or nearly all forms of viewing imagery. For example:

(1) All microscope work, especially continual peering, and especially by persons who wear glasses. Contact lenses would help, but even they cause their own set of discomforts.

(2) Viewing photos by transmitted light on projection screens or light tables when light shines into eyes through or at sides of film.

(3) Miscellaneous muscular stresses when equipment and/or photos are placed so that a person has to hunch over or bend his neck at a sharp angle for any length of time. Besides causing discomfort, cramped posture tends to interrupt circulation, leads to headaches, etc.

(4) All forms of improper stereo, including: images which do not correspond in scale (even within the 10 percent "limit") or orientation; images which do not have proper stereo base (i.e., flight line not the same in sequential coverage); images which have very great parallax exaggeration or which have so much relief that only parts can be fused at one time; blink comparison, if done as any more than an occasional stunt to find an elusive image; and probably, flicker fusion. Binocular fusion is supposed to be the most delicate adjustment the visual mechanism is required to make. Even in work with good stereo pairs, we abuse it in a mild way in the process of orienting the photos.

(5) Superimposition of images which do not exactly register, as in negative-to-positive change detection. It is understood from Colwell that when this was tried they ran out of interpreters in a remarkably short time.

(6) Long-continued work in dark rooms.

(7) Projection, especially rear projection, of moving images, as in scanning film with the film drive in operation.

Of course, people can cope with a certain amount of physical discomfort if they see good reason for doing so. However, it is difficult at the moment to think of another profession in which each technical innovation piles these stresses up higher. In addition to this, visual discomfort is far more alarming to the person than ordinary muscular strain. If his neck aches he may not mind too much, but if he begins to see double, he is rightly agitated.

It would be interesting to have a reliable account of the number, frequency, and seriousness of mistakes made under various conditions of intelligence interpretation. Undoubtedly many serious mistakes have gone undetected because there was no way to check up. Some of these, of course, are due to honest intellectual error (i.e., misinterpretation of ambiguous evidence),but many others must be due directly to the inattentiveness with which the mind protects itself from unacceptable stress.

Along this line, it is interesting to cite a relatively recent experiment in "visual factors" by the Geological Survey where they took a sufficiently existential view of their photogrammetric plotters to ask their opinions of the various tasks and working conditions (Moore and Bryan, 1964). The most interesting thing about this article is the tone of mild surprise throughout. The results were in fact highly predictable, but had remained hidden from the Survey as long as they viewed the work merely as a series of mechanical processes. For example, the Survey had never considered that they should supply corrected red-blue lenses to people with eye defects. Instead they made people choose between using clip-ons (uncomfortable and ineffective) and buying their own. At their salaries, naturally no one bought his own. Not until 1964 did the Survey (officially at least) discover that properly-fitted glasses improved a person's work. Similarly, when scribe coat materials first came in, they were eagerly adopted as a great boon to map production, and did in fact make a dramatic improvement in color separation and other reproduction methods. The fact that scribing violated all the draftsman's principles of fine muscle control through relaxation, and forced him to peer at his work at abusively close range to see what he was doing, was obvious to anyone who ever tried it; but not until 1964 did it occur to the Survey that loupes might help.

The Survey experiment led to a measurable improvement in performance of the experimental group. The experimenters seem to assume that this is due directly to the newly introduced working methods, and much of it undoubtedly is. But part of it must also be due to the improvement in morale of employees who had the novel experience of being consulted about their work. (In industry it has often happened that the performance of experimental groups kept going up, no matter what changes were introduced, even when all changes were abolished and the original conditions restored.)

2.1 Man-Machine Factors

The primary objective of this project has been to sift through the technical literature and research on visual factors for those factors relevant to the task of image interpretation. Assumedly, these factors are then applicable to design considerations of interpretation equipment, systems or operating environment. The phenomenal growth of technology and development of image exploitation equipment in recent years can only be expected to continue, probably at an ever accelerating pace.

At the risk of becoming involved in all the complexities of human factors engineering, it is perhaps useful to try to assess the relationship between the image interpreter and his equipment. One of the references reviewed during this project presents an interesting summary that could be germane to this relationship: <u>Human Factors Design Standards for the Fleet Ballistic Missile Weapon System</u>, Volume 1, "Design of Systems." Although this manual was written to cover a wide scope of applications and is therefore very generalized, its very nature as a tutorial contributes to its value. One section of it contains a somewhat philosophical discussion that neatly synthesizes many volumes of human factors texts. With judicious reading between the lines and a sometimes loose interpretation or application, many of the comments can be thought of in terms of the image interpretation/equipment relationship. For this reason, we have selected passages from this work for reproduction here:

2.1.1 Sensing

The sensing function consists of the detection of some physical energy (<u>information</u> or <u>signals</u>) originating within the environment of a system. These signals may originate external to the system: in radar or sonar returns, or in the human senses of vision, hearing, smell, etc. They may also be developed internal to the equipment, as in the result of switch closures in equipment or the kinesthetic sense in man. In either case, specific sensors are required to receive these signals as inputs to the system. The sensing function is often coupled with transducing, converting, filtering, or amplifying functions. Equipment examples abound, as in the transformation of a mechanical signal to an electrical signal, analog to digital conversion, selection of some portion or all of a signal for amplification, or screening out some undesired portion of a signal component (e.g., noise).

An important characteristic associated with human senses is the phenomenon of attention. Although the human being is constantly receiving sensations from many sources, he is able to select and concentrate on only those which are of importance to him, much as equipment sensors are able to filter out various unwanted signals or noise, or to select desired signals. In addition to attention, the reception of stimuli is influenced by a man's physical condition (i.e., health, fatigue), as well as by the range of sensitivity of the receptors.

The phenomenon of attention is closely related to the concept of perception. Human reception of signals would be meaningless without some basis for their interpretation. This interpretation becomes possible as a result of experience or learning. This association demonstrates another characteristic of human perception, that of the symbolic processes associated with it. Through man's ability to abstract significant details of complex inputs and to remember them, he is able to apply his experience to other situations (i.e., he is able to learn). Unlike equipment, perception in man is also influenced by emotional processes. For example, the performance of a particular task may be enhanced or degraded depending on the pleasant or unpleasant memories associated with it.

Thus, the function of perception in human beings is somewhat similar to those of transducing, filtering, and amplification in hardware systems.

2.1.2 Processing

After the information has been transformed into inputs suitable for use in a system, it is processed to produce appropriate outputs. The information-processing function may involve any or all of the following subfunctions:

(1) Measuring (estimating) and comparing external signals against each other or some stored standard of comparison.

(2) Integration of various signals with each other and with various alternative available actions.

(3) Storage of some or all of the information, to be acted upon later.

Transducing, converting, amplifying, and filtering again may be involved. Information processing in equipment may be performed according to pre-established fixed programs or may be under the control of a human operator. Often the rate at which information is received or can be processed is too great for the information at the time of reception. In these cases, data may be stored either temporarily or permanently, depending on the requirements for their utilization. In equipment memory there may also exist programs which provide instructions for processing the information.

Man is able to process information based on his perception of the signals which he receives and upon stored information. This integration of external and internal information,as the basis for identification or selection of appropriate courses of action, is often called decision making. Although decision-making tasks reflect an emphasis on only certain aspects of human information-processing capabilities, they have become a focal point for discussing man's processing capabilities. The processes which support the decision-making capabilities of man include abilities for qualitative estimations, comparisons, judgment, transformation, coding and decoding, inductive and deductive reasoning, abstraction and conceptualization, memorization and recall, and prediction. The result of these capabilities is to make man much more <u>flexible</u> than machines as a data processor -- at least in the present stage of technological development. Through appropriate training, man is able to deal with changing situations and unforeseen problems in the absence of a specific program. Unlike a computer, man can continuously develop and modify his own programming. In other words, he can learn. Closely associated with man's decision-making function is his <u>memory</u> or storage capability. Memory is the retention of what is learned and, conversely, forgetting is the failure to retain what is learned. Without memory, at least in the biological sense, there could be no learning; each occurrence of a signal would elicit the same response as before and there would be no modification or reprogramming of behavior. The capability of man to remember and to modify his behavior through learning accounts for much of his flexibility as a programmer of computers. Much of what is remembered, and the ability to manipulate and combine this information (thinking and reasoning), is the result of man's <u>symbolic processing</u> capability. What is retained is in the form of words, numbers, or images which represents abstractions or symbolizations of what is learned. This capability for abstraction and conversion to symbols of large amounts of information accounts for much of man's superiority over machines in decision making.

2.1.3 Actuating

Once a desired action has been identified or selected as a result of information processing or decision making, it is necessary to implement this action. Regulation in man involves the organization or patterning of his responses so that they will occur at the proper time, in the proper sequence, or in the proper combinations. For example, when learning to perform a procedure, an operator must refer to manuals or otherwise seek guidance to learn how to perform the procedure. Eventually, these responses become sufficiently learned so that the procedure is performed rapidly and accurately as a perfected and completely organized skill without any external supports. As skills are mastered, they are performed more and more automatically and involve less conscious effort or thought on the part of the individual. For the learning of complex knowledges, as might be required for high-level decision-making tasks, a similar organization of responses may take place if similar situations occur often enough; otherwise, man may exhibit considerable variability and disorganization in his behavior.

Also related to the regulation function in systems is the concept of feedback. Many semi-automatic or automatic devices or systems have one or more sensing or monitoring circuits which feed back information on the operation of the system to provide a basis for regulation and action. Such feedback loops are the distinguishing feature of closed-loop systems as opposed to open-loop systems. In many systems a human operator or monitor is depended upon to close the loop. Responses within the human himself, as with closed-loop hardware systems, exhibit feed-back characteristics. This is generally referred to as knowledge of results and may be of two general types: internal, resulting from sensations associated with bodily movements or the higher mental processes, as might occur in the mental solving of some problem; and external, resulting from seeing or hearing the results of his responses such as the change in position of control, change in the status of an instrument, or change in position of a vehicle.

Finally, to achieve the output -- whether it is information, materials, or control of other equipment -- all systems have one or more actuation functions. These require a supply of requisite energy in a form necessary to achieve the output. In man, this final phase of the behavior process is the evocation of some muscle response, either verbal as a command, or as a motor response such as the movement of the arm and hand to activate a control, or the movement of the eyes to view some display. Glandular responses also occur but ordinarily are of less importance from a design standpoint; however they do affect the level and type of activity of the individual as well as his comfort.

Two other categories of functioning peculiar to humans should be mentioned, those of drive and motivation. Drives include such factors as hunger and thirst and are related to the physiological requirements of the human organism. Motives are requirements which arise out of the individual's learning drives, and motives function as energizers of human behavior, and as such they are somewhat analogous to the power required by hardware systems for activation.

2.1.4 The man-machine interface

2.1.4.1 Capabilities and limitations of man and machine.

The table on the following page summaries the relative advantage of men and machines with respect to the basic task elements just discussed.

Following is a series of general principles taken primarily from discussions by Swain and Wohl after Fitts, together with some additions and comments pertinent to the assignment problem in general.

2.1.4.2 Characteristics tending to favor humans over machines.

(1) Ability to detect certain forms of stimuli. The ability to detect certain stimuli (e.g., smell, taste), especially stimuli which are not readily sensed inorganically, is one of man's characteristics.

(2) Sensitivity to a wide variety of stimuli. Man is sensitive to a wide variety of stimuli through the use of the organs of sight, hearing, smell, touch, temperature, pain, taste, balance, and muscle sense (kinesthesis). All of these sensory abilities are used in operating and/or maintaining equipment, though obviously some are used much more than others. In spite of this wide variety in sensitivity, the precision of sensitivity in any one mode is quite restricted compared to machine "sensing ability."

SUMMARY OF SIGNIFICANT MAN-MACHINE FACTORS

Advantages of Humans	Task Element	Advantage of Machines
Detect low levels of energy Sensitivity to a wide variety of stimuli Perceive patterns and generalize from them Detect signals in a high-noise environment	SENSING	Sensitiveity to stimuli outside of man's ability Insensitivity to extraneous factors Monitoring of other machines or men
Store and recall large amounts of information Exercise judgment Improvise and adopt flexible procedures Handle low probability events Arrive at new and different solutions to problems Profit from experience Track under a wide variety of situations Perform when overloaded Reason inductively	PROCESSING	Respond quickly to control signals Store and recall large amounts of data for short periods Computing ability Handling of highly complex parallel operations Deductive logical ability
Perform fine manipulations	ACTUATING	Perform routine, repetitive, precise tasks Exert large amounts of force smoothly and precisely

(3) Ability to perceive patterns and generalize about them. Man has this ability, even though the patterns may change in size or position or may be partly masked by noise. However, this ability (perceptual constancy), as it applies to certain types of activities, is often difficult to learn. Interpretation of patterns of light by human operators (sometimes required by certain computer programs) may be extremely difficult to learn. Waveform analysis is considered by many maintenance technicians to be the single most difficult perception required in test and checkout, and differences of opinion often exist between technicians in interpreting waveforms. Therefore, it is ordinarily advisable to search for ways to avoid waveform or light-pattern analysis, especially where relatively low-skilled personnel may be employed. However, if data can be encoded and displayed in such a way that the personnel can use their perceptual capability to the maximum (i.e., if adequate "pictorial" or familiar "patterned" displays are used), then they will be very good at sizing up complex situations quickly.

(4) Ability to detect signals (including patterns) in high-noise environments. This ability is related to the use of various types of operational cathode ray tube displays, to much aerial photography, and to reception of auditory signals. One shortcoming to this human ability is the human tendency to fill in gaps in the displayed information on the basis of expectancies. When these expectancies are not valid, the human operator or technician may see something that is not there or may miss out-of-tolerance indications not in line with his erroneous expectancy. This human limitation applies mostly to monitoring tasks, somewhat less to routine operating and maintenance tasks, and least to trouble location tasks where the man knows something is wrong and is searching for out-of-tolerance indications.

(5) Ability to store large amounts of information for long periods and to remember relevant facts at the appropriate time. This ability is related to the human's superior ability to use judgment, to improvise, and to respond appropriately to low-probability occurrences. The human is said to be capable of storing from 1.5 million to 100 million binary bits of information. Man's memory of facts is less reliable than machine memory, but he does fairly well at remembering principles, strategies, contingencies, and other rules and their applications, provided he has been properly taught.

(6) Ability to use judgment. It is difficult to define "judgment", although we all seem to know what it is. Perhaps man's superior ability to use judgment is related to his ability to handle concepts, ideas, and other

data which are not easily quantified, and to arrive at a decision on the basis of some unspecifiable comparison of nebulously defined alternatives, even when the situation is unique. Machines are not yet very efficient in the kind of selective, long-term storage needed for handling unique problems, and they cannot be fed any variable that cannot be encoded. Thus, judgment is very important where the population of events cannot be completely defined.

(7) Ability to improvise and adopt flexible procedures. The human can reprogram easily and quickly and can vary performance tolerances quickly. He can acquire new methodological know-how simply by reading printed verbal procedural directions. Human flexibility helps avoid complete breakdown in emergencies.

(8) Ability to handle low-probability alternatives (i.e., unexpected events). The human may not always employ an adequate strategy in dealing with rare events. In fact, he generally tends to try several strategies which have worked before for more familiar events, and he tends to repeat unsuccessful strategies or to just "Easter egg" (i.e., attempt random activities). This characteristic is not restricted to relatively unskilled personnel. If low-probability events can be programmed into a machine, the machine will be more efficient, because there is no forgetting. However, if the population of possible low-probability events is large (the usual situation in command/control and checkout operations), then the storage capacity required to handle them poses problems for the machine. On the other hand, properly designed procedures, coupled with adequate training, can markedly increase the average man's facility to respond to the unexpected.

(9) Ability to arrive at new and completely different solutions to problems. The human can employ originality in putting to use incidental intelligence picked up during his training or experience. Unfortunately, he sometimes may try the novel when the usual would be more appropriate. This partly explains the often-observed tendency for the technician to "tinker" and for the operator to "over-adjust" rather than follow the prescribed procedures. Probably a more complete explanation should also refer to the usual inadequate design of procedures.

(10) Ability to profit from experience. Ability to profit from experience, that is, to modify responses on the basis of prior events, is another of man's characteristics. It is not used to its maximum in operating and maintenance situations because of lack of a formal organization and procedure for incorporating and disseminating a body of operating or maintenance knowledge. Thus, system management policies will often prevent a system from

taking advantage of experience. Although machines have been built that can "learn" from experience (e.g., chess players and maze runners), the cost and volume required for such machines is much greater than for an equivalent man

(11) Ability to track (i.e., act as a servo follow-up) in a wide variety of situations. The ability to track (i.e., follow or center a moving target) is more pertinent to operator positions than to maintenance positions.

(12) Ability to perform when overloaded. The human is capable of withstanding high conditions of loading that might cause a complete breakdown in a machine. That is, the human frequently can perform at a less optimum rate or at a lower level of proficiency under high-load conditions, but he usually can continue to perform. This quality of "graceful degradation" is found in some machines, but to a lesser degree than in humans. However, this human ability is related to man's ability to generate his own inputs, and the negative side of this ability is the possibility that these inputs may be irrelevant to a solution. Thus, the human introduces internally generated "noise" to the man-machine system, and this can be part of the "overload".

(13) Ability to reason inductively. Man can reason inductively; that is, make generalizations from specific observations. Along with judgment, this is perhaps man's greatest claim to fame. It is especially important in decision making.

(14) Ability to perform fine manipulations. This superiority of man is especially important in assembly/disassembly operations, fault correction (e.g., soldering, replacing tubes, etc.) and in the fine adjustments required in calibration and alignment. Machines built to perform this type of manipulation are frequently extremely costly and complex. However, precise manual adjustments often must be aided by a machine; for example, a receiver tuning device or a torque wrench with a read-out in foot pounds. And those manipulations involving complex eye-hand coordination are difficult to learn to a high skill level.

2.1.4.3 Characteristics tending to favor machines over humans

(1) Sensitivity to stimuli. Machines can sense forms of energy in bands beyond man's spectrum of sensitivity; for instance, infrared and radio waves.

(2) Insensitivity to extraneous factors. Machines have a greater insensitivity than man to extraneous factors. They have no morale problems. They do what they are told to do. Perhaps this is at once the machine's greatest advantage and its greatest disadvantage. The advantages tend to be

emphasized by design engineers, especially those who have seen equipment misused in the field. The disadvantages tend to be emphasized by field personnel, especially those with high levels of skill who see aspects of this skill being replaced by machines.

(3) Monitoring other men or machines. A great deal of research evidence (both experimental and field observational) collected by North American and British researchers shows that man is a poor monitor of infrequently occurring events as well as frequently occurring events over a long period of time. Man becomes distracted or just bored. The evidence is so overwhelming that Fitts, et al., have declared that machines should monitor humans rather than vice versa. This principle has important implications for the design of semi-automatic equipment, as will be discussed in the next major heading. A corollary to the above principle is that man should not be the sole check on the accuracy of his work.

(4) Responding quickly to control signals. Machines have microsecond lags, whereas the shortest which can be expected from man is about 200 milliseconds, and this only if he is set to make a movement upon the receipt of a go/no-go signal. If a decision is required, the human response time increases rapidly. Moreover, man becomes fatigued rapidly under conditions requiring a series of rapid decisions. Speed, then, is one of the primary qualities of machines.

(5) Storing and recalling large amounts of precise data for short period of time. Especially in the computer field, there are requirements for short-term storage of information ("scratch pad" data), followed by complete erasure of the data in preparation for another task. Machines excel at this; humans not only have difficulty memorizing large amounts of information, but their recall is often spotty and they have difficulty in completely erasing information in short-term storage.

(6) Computing ability. People make errors even in the simplest conversions of data requiring no more than simple arithmetic. They are poor at quickly performing highly complex calculations. Such calculations as higher order integrations pertinent to some types of navigation and fire control computations, are beyond the capability of humans. However, machines are limited by the rules of operation that are built into them. In some cases, humans can arrive at an adequate answer more quickly by a series of approximations that eliminate unnecessary precision.

(7) Handling of highly complex operations (i.e., doing many different things at once. Fitts, et al., states that when man has to employ his highest intellectual abilities, he is essentially a one-channel computer -- he can work effectively at solving only one problem or attending to one thing at a time. Only when he achieves very high degrees of skill can he work on more than one thing, and then only by rapidly shifting back and forth. The machine, however, is limited only by the capacity built into it.

(8) Deductive logical ability. Machines are much quicker and more reliable than humans in identifying a specific item as belonging to a large inclusive class and in using rules for processing information. If an operation can be programmed 100 percent, then a machine can be built to perform the operation rapidly and accurately with perfect repeatability. However -- and this is often overlooked -- procedures can be built to enable a human to follow the rules efficiently, though less rapidly, and with a small probability of error.

(9) Performance of routine, repetitive, precise tasks. Man is notoriously prone to commission of errors in such operations. As in monitoring tasks, he becomes easily distracted or he may perform some non-prescribed action out of sheer boredom. However, if the task is sufficiently repetitive that it can become automated, then the operator's involvement in and awareness of what he is doing can be reduced to a minimum and he is free to think of other things.

(10) Exerting large amounts of force smoothly and precisely. The human is no match in strength for even the simplest lifting or moving devices, and his control movements with large objects tend to be erratic and subject to oscillation, especially when the emphasis is on speed.

3. COLOR VISION

Discussing the complexities of color (see Dimmick, 1964), Hering, in 1878, pointed out that the physical, the physiological, the psychological, and the "common sense" concepts of color are completely different. "The layman," says Hering, "believes the green of a leaf to be a property of that leaf. The physically informed person, however, regards the green, not as an attribute of the leaf, but as a characteristic of the rays reflected from the leaf and names them green. The physiologist goes further. He knows that the green is not truly a part of the rays reflected to the eye but, instead, depends upon the visual organ. With the same validity with which the laity considers green as an attribute of the leaf, and the physicist regards the reflected green as a property of the rays, he speaks of a green impulse in the visual organ. Finally, for the psychologist, green is neither a property of the leaf nor of the ray nor of an impulse in the eye, but is instead a mental fact. To be sure, he grants it to be dependent upon a nerve process, but he discriminates between the postulated physical correlate of the phenomenon and the phenomenon itself."

The very narrow portion of the electromagnetic spectrum to which the eye is sensitive is generally considered to be about one octave, from about 380 to 760 $m\mu$, although wavelengths as low as 313 $m\mu$ and as high as 1 $m\mu$ may sometimes be seen. This objective, or physical, light is able to stimulate the retina, and the nerve impulses which it sets up, when conducted to the brain, evokes the sensation of light. When all the wavelengths within this visible band are present, the resulting sensation is that of white light. When these vibrations are separated by a prism or grating, a spectrum of the light appears.

As an introduction to the processes of color vision, it is worthwhile to review briefly the duplicity theory of scotopic and photopic vision, and the nature of the visual system. In particular, a knowledge of the characteristics and functions of the retina are essential to the study of color.

The photodetection system consists of a retinal mosaic of some 127,000,000 receptors. Of these, about 7,000,000 are cones which provide high-acuity daylight or photopic vision and color appreciation, and about 120,000,000 are rods which are highly sensitive to low-light levels and are essential to scotopic or night vision. The dark-adapted rods contain a material known as rhodopsin or visual purple which becomes bleached in the presence of light. This forms lumi-rhodopsin which, in the living retina, breaks down thermally to retinene and then to a protein called opsin. A form of the retinene also breaks down to vitamin A, passing out of the receptors into the pigment epithelium which, with the blood, resupplies vitamin A which in turn is needed to rebuild rhodopsin. Thus, the importance of an adequate diet of vitamin A is apparent. It is only necessary to understand, in an oversimplified statement, that the visual purple molecule, which is a union of a simple protein and vitamin A, undergoes decomposition under the influence of light. Some of the products formed stimulate the rods, directly or by the intervention of another chemical reaction, thereby generating a nerve impulse. In the absence of light, visual purple is resynthesized. Both the rebuilding and the decomposition take place simultaneously, the extent of each being determined by the intensity of the light. (Zoethout, 1947)

Exposure of the rods to light does not evoke the sensation of color. However, different parts of the spectrum, when viewed by the dark-adapted eye at low-light levels, appear to have different luminosities with the brightest region being near 510 mμ, or what would be the blue-green part of the spectrum. Longer wavelength red lights are hardly seen at all, with only slight improvement in the deep blue or violet regions. This relative lack of sensitivity to red light is the reason why pilots, for example, when preparing to fly night missions will spend some time becoming "dark adapted" in a room illuminated with red light. However, by reducing the energy of the illumination sufficiently, it probably makes little difference as to the color of the light. The main advantage is that when one color is used as the adapting stimulus, the eye gradually loses sensitivity to that color, so in general the blue-green region, to which the dark-adapted eye is most sensitive, is avoided as an adapting light.

The photoreceptors known as cones are considerably less sensitive than the rods and become active only at light levels of about 0.25 meter candles or greater. Under daylight or photopic conditions, colors can be seen, and the visual acuity improves. Cones are found throughout the retina but have a maximum concentration in a small central area known as the fovea, which is the region of maximum visual acuity. While there are some cones throughout the retina, there are no rods at all in the fovea. The maximum concentration of rods is about 20 degrees from the center. Thus, because of the cone distribution, some color can be seen near the periphery of the field-of-view if the light level is high enough. At very low-light levels, objects which cannot be seen at all by looking at them directly can sometimes be seen by turning the eye so that the more sensitive rods are illuminated.

Whereas the eye in scotopic vision is most sensitive to light at 510 mμ, it is most sensitive in daylight or photopic vision to light at a wavelength of 555 mμ. As a matter of fact, the whole spectral sensitivity curve shifts toward the higher wavelengths in photopic vision. This shift in spectral sensitivity is known as the Purkinje shift, or phenomenon.

For light to be seen it must first of all be absorbed by a photopigment in the eye, which produces some change capable of starting the complex neural events involved in vision. Chemistry of rod photopigment has been studied in detail; color vision, which depends mostly on the cone photopigments, has been notoriously difficult to investigate. (De Valois and Abramov, 1965)

A color is generally characterized by three qualities: hue, brightness and saturation. However, as Evans (see De Valois and Abramov, 1965) pointed out, with a spot of light on a background one no longer has a simple three-variable color vision system. The colors perceived in various stimulus situations involve manipulation of six psychophysical variables of luminance, purity, and dominant wavelength for both the stimulus and the surround, and this in turn presents four independent variables: the three mentioned above of hue, saturation and brightness, but also grayness, with each quality influencing the other.

Hue is that sensation determined by wavelength which is what is ordinarily meant when the word "color" is used. The general recognizable hues are named red, orange, yellow, green, blue, indigo and violet. Each of these merges by imperceptable gradations into its neighboring color. Red gradually changes to an orange-red, reddish-orange and then to orange, and so on without specific boundaries. Actually a large number of hues can be recognized, but only a relatively few receive names.

There are certain portions of the spectrum where small differences in wavelengths give rise to large differences in color sensation. Hue discrimination is particularly acute in the yellow, near 585 mμ, and somewhat less so near 497 mμ in the bluish-green. There are also two much smaller peaks in the orange (636 mμ) and blue (435 mμ), but elsewhere hue discrimination or hue sensibility is much less acute. At each end of the spectrum, beyond about 655 mμ at one end and 430 mμ at the other, there is very little change in color sensation as the wavelength is changed.

For each psychological phenomena (hue, brightness and saturation) there is a physical counterpart of wavelength, the physical intensity of light, and the absence of white light, respectively. Color names often refer to hue-saturation combinations, such as "pink," which is basically red but has a large white component and is therefore a desaturated red.

There are a number of pairs of colors which, when viewed together, produce white light and which, following exposure to one, produce an after-image of the other. Furthermore, adaptation to one color and then viewing another may produce "supersaturated" colors. These hues are known as complementary colors. Every spectral color, except for the greens, has a complementary color. Since complementary colors produce white in which the hue of each is destroyed, they mutually exclude each other. Thus, a reddish-green or greenish-red does not exist as does a greenish-yellow or yellowish-red.

While numerous theories have been advanced about why humans and a limited number of animals and fishes actually can experience the sensation of color, none have yet adequately explained this phenomenon. However, there is sufficient evidence, either implied or direct, which leads to the conclusion that there are very few different types of cones, each sensitive to a different color. The eye, unlike a spectroscope, cannot tell what the components of a particular color are. Any color, or hue, can be matched with no more than three primary colors in various amounts, forming what is known as a metameric match. (Sometimes, however, one of the colors has to be added to the color to be matched.) Furthermore, various combinations of red, green, and blue will give the appearance of white light. Because of these phenomena, most investigators have tended toward a three-component color theory. Indeed, MacNichol (1963) has found clinical evidence in the retinas of goldfish which tends to support this. Nevertheless, in recent years Boynton and others have proposed a four-component theory which also makes quite a bit of sense. It has been noted that there are four color sensations which are psychologically unique. These are known as the primal or psychologically pure colors of red, green, yellow and blue. To bolster the argument of four primal colors, it is noted that while color matches are maintained despite luminance differences, hue is likely to shift, with the notable exception of the four wavelengths which yield the primal hue sensations.

It is very interesting to note that in spite of these theories, Land, in 1959, dramatically demonstrated what appeared to be full color from only two wavelengths. Furthermore, it did not matter greatly what these wavelengths were to produce this phenomenon: just a long wavelength record and a short wavelength record. It has been stated that this occurs as the result of color contrasts, or the induction of one color by the color of its background. Whatever the cause, it is known that the apparent color is often influenced by the observer's memory of the scene, or by what he thinks it should look like. Also, the apparent color of a scene, which has been masked off, looks significantly different when the mask has been removed.

In 1959, after the appearance of Dr. Land's now famous article in the Scientific American, the principal investigator, along with D. S. Ross, extended the idea of a "long" and "short" record to a combination of infrared and monochromatic visible light to produce some startling results having application in camouflage detection.

The so-called Land process of recording photographic images using a two-color separation process and recombining with the same colors, or almost any colors desired to produce "natural" or "false" colors, finds important applications in reconnaissance photography. The process has the possibility of providing two very high resolution black-and-white negatives which can be viewed as is or recombined as a color representation of the original scene. This technique can often yield higher resolution and sometimes better color rendition than a conventional color film pack.

4. FATIGUE

The common meaning of "fatigue" -- the subjective sense of tiredness -- embraces three things: true physiological fatigue, or the state of one's metabolism; visual adaptation (often erroneously called "visual fatigue") or the state of one's receptor cells; and an individual's mental/emotional attitude at a given moment. Of the three, assuming that a person is not absolutely disabled from true fatigue, the last is probably critical in working circumstances. However, it is not amenable to study. Visual adaptation is responsive, but its applicability to the PI operation is not entirely clear.

Zoethout states that the physiological state of fatigue of the bodily structures reflects itself in the psychological sensation of fatigue which may be either general or local. General fatigue is often experienced at the end of the day, even though this has not been spent in any great degree of physical or mental exertion. Local fatigue is associated with the physiological fatigue resulting from the continued and fairly rapid activity of certain muscle groups. However, regarding the visual apparatus, actual retinal fatigue has never been demonstrated. Ocular fatigue, or so called "eye strain" manifests itself by the well-known symptoms of a dryness and a smarting of the eyes, often accompanied by eyeache and headache when the work is very severe. Actual visual acuity is only slightly affected, if at all, during periods of long observation. Also, the amplitude of convergence was found to be virtually unchanged in a large majority of subjects tested.

The subject of fatigue, as commonly understood, in delicate visual tasks such as photointerpretation is admirably summed up in one sentence in the book by Le Grand: "Fatigue, which is a reduction of activity due to an accumulation of waste products which the body must get rid of in order to regain its energy . . . .being almost inappreciable for a certain time but then showing a progressive lowering of activity."

What is often meant by "vision fatigue" is really "efficiency time." If we kept strictly to "vision fatigue" we may quote Davson to the effect that when a subject is tired or unwell his range of uncertain seeing increases. This is the range within which he is likely to fail to detect a weak stimulus, to report that he detects a stimulus when in fact there is none (this happens in the most faithfully controlled experiments), or both. In fact the unreliability of experimental subjects, who report "seen" when there is nothing to see, could be rather directly applicable to PI working conditions.

4.1 Sensory Deprivation

Certain effects or phenomena which are often attributed to "fatigue" are more properly traceable to sensory deprivation. This has nothing to do with "vision" as such, but a great deal with perception and cognition.

The subject came up during the war in studies of the visual inefficiency of radar operators, and seems also applicable to photo-interpretation. From these studies we have an interesting example of the effects of combined physical monotony and emotional pressure on radar operators (Heron, 1957). Men on anti-submarine patrol sometimes failed to find U-boats, which did, in fact, appear on the radar screens. These men worked in isolation, watching the screen continuously for long shifts. A laboratory experiment was constructed, duplicating the combat situation as nearly as possible. The experimental subjects' efficiency in detecting images declined seriously within half an hour.

Of course the trouble with this experiment is that it reproduces the monotony, but not the pressure of imminent danger on a passive individual. Danger used to be considered a stimulus to alertness, and probably correctly so in the days when the appropriate responses were active ones. For the radar operators, the stimulus (if any) of imminent danger was ineffective against physical monotony; or perhaps contrariwise, instead from stimulating them to alertness it combined with monotony to reduce their efficiency.

An interesting series of experiments has been done on the effects of sensory deprivation on the mind. Subjects placed in a rigidly monotonous environment suffered almost immediately from impairment of thought, presently from delusions of persecution and alarming hallucinations. (Complete darkness and silence proved less damaging than dim diffuse light and low continuous noise.) When restored to normal environment after several days, the subject suffered severe perceptual derangements: apparent movements of objects, distortion of shapes and colors, and continued hallucinations whenever they closed their eyes. Some people were affected to the point of nausea or fainting. In fact, these people experienced a temporary disintegration of the personality. Similar hallucinations have also been reported in experiments which exposed subjects for long periods to blank visual fields or flickering light.

The experimenters (Heron 1957 and others) concluded that the normal functioning of the brain depends on a continuing "arousal" reaction maintained by a constant bombardment of sensory stimuli. However, the stimuli lose the power to maintain this arousal if they are restricted to repeated stimulation in an unchanging environment.

Photointerpreters in scientific fields are protected from some of the above conditions. Photointerpretation for the scientist is not a profession, only one of many techniques. He does not indulge in much experimentation with sophisticated viewing methods. He is not usually under emotional pressure. He is free to study and consider the photographic images on his own schedule; he can drop photointerpretation for study or field work whenever it seems desirable; and he is internally motivated by intellectual interest in the images he looks at. However, the motivations which act on intelligence interpreters are extremely varied and virtually impossible to categorize or measure.

5. STEREO VISION

Stereopsis as a visual process in image interpretation involves a complex mixture of physiology, perception and psychophysics of vision.

Time limitations have prevented an exhaustive search and compilation of the literature on this topic for this project along with any succinct summation of finds. A thorough analysis and presentation of this topic alone could be a separate project of considerable magnitude.

As a preliminary indication of research performed in this area, selected references are listed below:

M. H. Salzman, "The Place for Vision Testing in Photogrammetry", Photogrammetric Engineering, Vol. XVI, No. 1, pp. 82-94.

A. Anson, "Significant Findings of a Stereoscopic Acuity Study", Photogrammetric Engineering, Vol. XXV, No. 4, pp. 607-611.

R. F. Dwyer, "Visual Factors in Stereoscopic Plotting", Photogrammetric Engineering, Vol. XXVI, No. 4, pp. 557-564.

Joseph B. Theis, "A Key Link in the Photogrammetric Chain - The Human Being", Photogrammetric Engineering, Vol. XXIX, No. 2, pp. 253-258.

Elton J. Gumbel, "The Effect of the Pocket Stereoscope on Refractive Anomalies of the Eyes", Photogrammetric Engineering, Vol. XXX, No. 5, pp. 795-799.

Sandor A. Veres, "The Effect of the Fixation Disparity on Photogrammetric Processes", Photogrammetric Engineering, Vol. XXX, No. 1, pp. 148-153.

Kenneth N. Ogle, "Stereoscopic Depth Perception and Exposure Delay Between Images to the Two Eyes", JOSA, Vol. 53, No. 11, November 1963, pp. 1296-1304.

Duane Lyon, "Let's Optimize Stereo Plotting", Photogrammetric Engineering, Vol. XXX, No. 6, pp. 897-911.

APPENDIX A

SPIE SYMPOSIUM "THE HUMAN IN THE PHOTO-OPTICAL SYSTEM" ABSTRACTS AND COMMENTS

On April 25-26, 1966, the principal investigator attended the "Human in the Photo-Optical System" seminar in New York, presented by the Society of Photo-Optical Instrumentation Engineers and co-sponsored by the United States Army (GIMRADA). The program indicated this was to be "a seminar-in-depth devoted to the manner in which data is optically presented to an observer and the way he analyzes or interprets that data." For the most part, this was true, although some of the papers strayed either into border areas of industrial sales promotions or into regions of psychology where the practical significance was not particularly evident.

It is felt that it would be sufficiently worthwhile to reproduce the abstract of each paper as it appeared in the program, along with some comments of the investigator. Not all of the papers listed in the program were actually presented, but the abstracts appeared interesting enough to warrant publication with the rest.

The seminar keynote address was presented by Captain John K. Sloatman, Commanding Officer and Director of the U. S. Naval Training Devices Center, Port Washington, N. Y. He stressed the need for simulation fidelity in training. To satisfy this fidelity he stated that psychological and physiological studies are necessary to determine what visual skills are important and what can be presented in nonenvironmental training. He emphasized the requirement for realism in fire control trainers, aircraft simulators, and the like.

SESSION I
VISUAL REQUIREMENTS IN PHOTO-OPTICAL SYSTEMS
Session Chairman: Dr. Joseph Zeidner, Army Research Office

THE ROLE OF THE HUMAN FACTORS SCIENTIST IN DETERMINING VISUAL REQUIREMENTS FOR PHOTO-OPTICAL SYSTEMS

Dr. Jerome Siegel, Chief - Human Systems
Systems Management Division
Kollsman Instrument Corporation
Elmhurst, N. Y.

"There is very little awareness that the majority of Psychologists working as Human Factors Scientists have been trained in a broad spectrum of the behavioral sciences. A very critical part of this training is in the area of vision. This knowledge can be extremely significant in generating visual requirements for the design of photo-optical equipment which is to be used by an operator.

"The Human Factors Scientist first takes a very meticulous look at the system and mission requirements and corresponding tasks which are to be performed by the optical equipment/human eye interface. On the basis of certain empirical data, such as visual acuity curves, visual threshold data, contrast discrimination relationships and visual perception data, a number of preliminary conclusions can be made concerning the visual input requirements necessary for the photo-optical system so that an operator can successfully perform his task to satisfy mission requirements. Several specific examples using classifical visual curves will be presented to demonstrate how visual requirements can be established using analytical and experimental techniques. These illustrations will include studies on an optical viewfinder for lunar target detection; a target detection problem using a TV display system; a missile tracking radar display system."

Comments:

Dr. Siegel indicated that most human factor studies are geared for vision. Relationships such as that of stimulus-response, familiar in psychology, apply in such visual functions as brightness thresholds. The trade-off factors in equipment design are based on knowledge of human visual, physiological and psychological factors. Among these factors are a knowledge of the functions to be performed, the control actions required, and operator task requirements. In addition, information is required regarding environmental data, weight, size, target shapes, color and motion. Among the system variables to be considered in equipment design are the field of view, magnification, resolution, contrast, look angle, and monocular or binocular viewing.

PHOTOGRAPHIC STIMULUS MATERIAL AS A PSYCHOPHYSICAL TOOL

John F. Coughlin
Perkin-Elmer Corporation
South Wilton, Connecticut

"Controlled studies that seek to explore the role of the human observer in the evaluation of photographic images are possible only when stimulus material is employed whose objective quality is well known. When such studies involve the imagery of complex photo-reconnaissance systems, the necessary stimulus material is difficult to acquire due to the variability in image quality and inadequate means of evaluating such images.

"In view of these difficulties, techniques have been developed whereby the prerequisite stimulus material can be prepared in the laboratory by simulating the characteristics of the photographic system. These techniques will be discussed, typical stimulus material will be displayed, and applications in the field of psychophysical experiments will be considered."

Comments:

Mr. Coughlin described the laboratory preparation of photography for psychophysical stimulation. In this context, the psychological aspect meant data extraction from photographs, and the physical aspect was in regards to the actual film/camera characteristics and the photographic image.

To generate variables for simulating conditions which might be expected in operational systems, it is possible to alter photographs by altering the transfer function. The technique basically consists of projecting a source energy distribution through a pinhole aperture to an image energy distribution. The aperture plane can be apodized, or controlled in transmission. The combination of aperture transparency plane control, along with control of the object energy distribution, produces an output related to the convolution of the spread functions of the source and aperture. Through this technique, various models can be generated which can include, among other things, the effects of haze and film granularity. It was pointed out that it is possible for someone to extract considerable detail from even a badly degraded image.

DEVELOPMENT AND EVALUATION OF A NEW TECHNIQUE FOR MEASURING IMAGE QUALITY

Dr. Robert Sadacca and Dr. Robert Brainard
Army Research Office
Washington, D. C.

"An image catalog containing a standard set of images having diverse scene content and quality was developed. Each image in the catalog had associated with it indices of image interpretability based on measures of the performance of interpreters who previously interpreted the images.

"In application, the catalog approach requires an interpreter or other judge to compare any new or "test" image being assessed with images in the catalog and to select that catalog image most similar to to the "test" image in regard to judged image quality. The indices associated with the selected image are then taken as measures of the interpretability of the "test" image.

"This catalog technique for the measurement of image quality proved quite valid and compared favorably with techniques using judgement for physical variables alone."

Comments:

The authors sought a quick means to determine image quality for photointerpretation screening operations without elaborate mensuration equipment. The technique is to assess image quality by comparison with a catalog of images. This provides an "index of interpretability" as a measure of image quality.

The catalog concepts were:

1. Humans can judge image quality.
2. Judges should be provided a standard context.
3. Image quality means image interpretability.
4. Sample of images from a population of scenes.
5. Sample of image variants from a given scene.
6. Physical, judgmental, and performance variables are properties of image variants.

It was interesting to note that the image catalog did not contain variables in contrast because, over the range of interest, contrast had little effect. Ground resolution and scale were the most important variables and provided the best correlation with the catalog. While the point was not clear, it appeared that in a tactical reconnaissance situation, the photographic coverage with the best scale and ground resolution would be examined first, since it would be most likely to contain interpretable information. This would assume there would be multiple coverage of a given target area and that these basic criteria could be used in selecting photos for further examination.

THE HUMAN OBSERVER

J. M. Heyning
Litton Systems, Inc.
Data Systems Division
Van Nuys, California

"This paper discusses the various aspects related to the visual capabilities and limitations of the human observer, covering both the physiological aspects as well as the engineering aspects. A brief outline of this discussion will present the following topics:

1. The physiology of visual perception in terms of the functional behaviour and control mechanism of the human eye. The former will be discussed in close analogy to that of a photographic camera, while the latter relates to specific functional requirements such as target fixation and target tracking in static and dynamic presentations. A discussion of the limits of resolution of the human eye will attempt to correlate the physical-optical and the physiological aspects.

2. The capability of the human observer to detect, recognize, and identify targets in real-time exploitation of airborne sensor data. This will be discussed in terms of a graphical presentation of critical target dimension versus observation time which can be employed for effective utilization of certain airborne sensors such as TV, IR line scanner, Laser line scanner, and radar. An analysis of display systems parameters relevant to dynamic imagery presentations and interpretation will also be discussed."

Comments:

The first part of the paper was a discussion of Derek Fender's work on eye tracking mechanisms and the eye as a servo system. (Part of this area had been previously explored in the December 15, 1965 - March 15, 1966, Human Factors Aspects of Photointerpretation report prepared by [redacted] under STAT this contract.) In the second part, the interpretation of dynamic imagery (i.e., real-time airborne sensors such as television and radar) was discussed. It was pointed out that in side-looking radar displays, for short observation periods, dynamic displays are most likely to result in target detection. For long periods of observation the reverse is true. With an image moving from top to bottom an observer tends to scan along the top edge.

CAPACITY AND OPTIMUM DIMENSIONS OF DISPLAYS FOR GROUP VIEWING

Dr. Helmut Weiss
Aeronutronic Division
Philco Corporation
Newport Beach, California

"This paper answers the questions: How much information can a display screen convey, how large an audience can it serve, and how should audience and screen be arranged relative to each other?

"It will be shown that in a display intended for group viewing the individual symbols must be large enough to be legible from a normal distance equal to the screen diagonal. This condition limits the capacity of the display, which is found to be independent of the size of the screen.

"Filled to capacity, a display can only be read from a single viewpoint. To accommodate a finite audience, it must be used below capacity. For a given display, there is a well defined optimum screen/audience configuration which allows the display to be read by the maximum number of people. If the utilization of a display is increased, its efficiency decreases (i.e., to permit the display of more symbols, the individual symbol must be enlarged).

"These relationships are important to the systems man, who should be aware of the limited capacity of a group display (and the cost of pushing its utilization too high), to the architect who lays out the audience, and to the designer who determines the parameters of the equipment."

Comments:

Dr. Weiss used the concept of "locus of legibility" to establish screen sizes for a given audience size and viewing distance. It can be shown that for vertical bar targets the locus of points of constant resolution is a circle tangent to the screen. This means that in the oblique viewing of vertical bars the spaces appear foreshortened and an observer must move closer to the screen to see bars with a constant visual angle. For horizontal bars, the locus of points of constant resolutions is a semi-circle with origin at the target on the screen. It turns out that a letter, whether it be vertical or horizontal, has the same locus of legibility, and this is described by the first case as a circle tangent to the screen.

The concept is expanded by considering "three-dimensional circles", that is, spheres, tangent to each corner of a screen which determine, at their intersection, the audience volume for a given visual range. By tilting the viewing screen, and putting the center at eye level, the maximum viewing volume for an audience can be obtained. This screen tilt is important at short visual range but not so important longer ranges. It was judged that better display information could be obtained by breaking a larger screen into smaller areas arranged around a circle.

THE ULTIMATE INSTRUMENT - MAN

Robert S. Scott (Guest Speaker)
Assistant Director
Government Relations
Aerospace Corporation
El Segundo, California

"Nearly 2500 years ago a Greek philosopher named Protagorus observed that 'Man is the measure of all things.' This unique idea appealed to Plato who taught his own students and millions more through the ages the challenging truth of this concept. We may not all agree with the ancient Greeks. We may not understand what they meant.

"However, we may agree that man is certainly becoming the 'measurer' of all things. What kind of an instrument is this man, in full measure? How do we calibrate his brain? How do we affect and control his reliability? What are his sub-systems? How is his operational efficiency affected by his ambient environment? Are these questions valid to the human evaluation of the total photo-optical system?

"Are we trying to instrument the man -- or man the instrument? How can the 'human' in the system improve system operation?

"What can be expected in the future from that living, evolving, 'ultimate instrument' called man?"

SESSION II
METHODS OF VISUAL PRESENTATION
Session Chairman: Desmond O'Connor, GIMRADA

VISUAL PRESENTATION SIMULATION REQUIREMENTS AND TECHNIQUES

Moses Aronson
Head, Visual Simulation Lab
U. S. Naval Training Center
Port Washington, New York

"The requirements for acceptable visual presentations by simulation techniques for use in training pilots and other vehicle operators are defined. The requirements will be defined in terms of the human operators' visual capabilities. Among the requirements to be discussed are: What is wide angle? Is color necessary? What detail is necessary? Light level of the picture; performance characteristics of the flight simulator or other vehicle simulated which are important to a visual display/simulator combination; limits of the visual world envelope; requirements for specific missions, simulator performance envelope and need for peripheral vision.

"The second portion of the paper will describe some visual simulation techniques and research hardware developed to date. The compromise and limitations of the equipment as well as advantages of various techniques will be discussed. The visual simulation techniques to be covered will include the shadowgraph/point light source, television and optical techniques for providing clear day or low visibility conditions."

Comments:

The need for both physical and perceptual fidelity in nonprogrammed, real world visual simulation systems was stressed. In such systems, it was pointed out that monocular cues are the most important. A visual aircraft simulator was described which had an enclosed cabin with a vertical periscope looking at a model on the ceiling of the room. This system provided high resolution and wide (76°) field but a small exit pupil.

VISUAL SIMULATION

Paul T. Kaestner, Vice President
Photomechanisms, Inc.
Huntington Station, L. I., New York

"When generating a display from a scale model for the realistic presentation of a view as seen from an aircraft or spacecraft, compromises with the real life situation are inevitable. These occur both in the initial imaging lens and in the final display. Factors such as resolution, light intensity and true perspective influence the imaging characteristics, while problems of parallax and image brightness limit the realism of the display. Fortunately, the choice of the compromises provides acceptable performance for most simulation systems.

"A typical simulation system will be described and illustrated."

Comments:

Mr. Kaestner described a telecentric optical system used for a simulation display. A series of prisms is used to provide pitch, roll and yaw motions. The image falls on an image orthicon for television display.

A CORRELATIVE METHOD FOR VISUAL PRESENTATION OF PHOTOGRAPHIC IMAGERY

J. K. Libby
Fairchild Space & Defense Systems

"This paper describes a recently developed system which enhances the human decision making capability in analyzing the interpreting aerial photography.

"Advanced tactical multi-sensor reconnaissance missions provide four separate rolls of film which require interpretation. Since each roll of film covers approximately the same area, it is advantageous to view all four at the same time, with each running at its appropriate speed so that the same images on all four rolls can be viewed simultaneously.

"The Multi-Sensor Viewer, with its various functions of comparison viewing of Tactical Target Records, mensuration, printing and processing, simultaneous scanning, and stereo-viewing will be described. In addition, a brief discussion of its integration within the Image Interpretation Cell will be presented.

"The Multi-Sensor Viewer was designed and developed as part of the Image Interpretation Center (IIC) AN/MSQ-58, for the Rome Air Development Center under Air Force Contract AF 30(602)-2882."

Comments:

The Multi-Sensor Viewer, installed in a van for tactical use, allows simultaneous viewing of panoramic, frame, infrared, and side-looking radar photography. Maps or other cues can be projected on a separate screen for reference. A mensuration capability with digital readout is provided, along with stereo viewing of the panoramic and frame coverage. Any one of the four channels can produce a hard copy print.

TRAINING AND STEREOSCOPIC PHOTOINTERPRETATION PERFORMANCE[1]

James R. Williams, Human Factors Scientist
Systems Management Division
Kollsman Instrument Corporation
Elmhurst, New York

"Since a previous review of the literature, concerning stereoscopic performance, had indicated contradictory evidence as to the utility of stereoscopic viewing in enhancing photointerpreter performance, KIC initiated an experimental program to investigate this problem. Careful analysis of the negative studies indicated that subjects were usually recent graduates of PI schools and had received relatively little training on stereoscopy or stereoscopic devices. KIC's approach was to first determine, via a pilot study, if training would improve stereoscopic PI performance, and then to experimentally derive training materials to optimally enhance such performance. Since pilot study results were favorable, KIC is presently engaged in investigating various training techniques. One technique which seems to offer many possibilities is the use of three-dimensional embedded figures. Preliminary data has indicated that subjects who have had some photointerpretation experience perform better on 3D Embedded Figures tasks than those subjects who have not had such experience. Improvements in performance with practice have also been noted. It is felt that the research with these figures may result in the development of a successful training approach and, possibly, an aptitude screening device for photointerpreters."

[1]This study was done in conjunction with Mr. J. Wilde and Dr. J. Siegel of KIC.

Comments:

Mr. Williams contended that the so-called three-dimensional embedded figure task may be useful for screening potential photointerpreters. He said that in many cases "stereo is a useful tool and should not be overlooked." Dr. Zeidner, from ARO, commented that Army PI's are currently screened by tests of stereo, visual acuity, reasoning, and spatial orientation. He said that such tests have been used by the Army for about 2 years and by the Air Force for 5 or 6 years.

POSSIBLE EDGE-ADJACENCY EFFECTS IN PHOTOGRAMMETRIC COORDINATE MEASUREMENT

Desmond O'Connor, Senior Research Scientist
U. S. Army Engineer
Geodesy, Intelligence & Mapping Research & Develop Agency
Research Institute for Geodetic Sciences
Fort Belvoir, Virginia

"This paper gives preliminary results of a continuing experimental study of factors affecting the precision of centering black circular measuring marks in sharp, high-contrast targets with homogeneous backgrounds, subtending visual angles up to 45 minutes of arc, in photopic vision. These targets are designed to simulate the task of measuring coordinates of artificial pass points in aerial triangulation.

"The results support the proposition that adjacency effects at edges contain significant visual information, and this would appear to be important where visual settings are being made by bringing geometrical configurations into close relationship with one another.

"The maximum information content for the centering task investigated was contained in ribbons approximately 1 minute of arc wide around the light areas of target and measuring mark. The most precise pointings were made by selecting a measuring mark to give a minimum annulus width within these ribbons irrespective of the target size.

"The results support the concept of a retinal zone approximately 4 minutes of arc in diameter over which acuity is constant, but further suggest that this may be dependent on the type of task involved.

"The acuity in the horizontal retinal meridian was some 30 percent greater than that in the vertical meridian for annulus widths up to 4 minutes of arc."

Comments:

This paper was particularly interesting and well presented. The abstract adequately describes the experimental program to determine the pointing error in centering a small disc within a circle.

The conclusion was that the pointing error in the Y-meridian (vertical) was about 1.3 times greater than in the X-direction.

The following abstract appeared in the program but the paper was not delivered at the seminar:

MEASURING ON PHOTOGRAPHS

Helen E. Gustafson
Nuclear Research Instruments
Berkeley, California

"Both instruments and humans are needed to extract dimensional data from photographs and convert it to numerical data for processing and analysis. The human, with his equipment, becomes the interface between the photograph and the computer. The job of an instrument designer is to effect a match between characteristics of the input and usefulness of the output. One component of this intermediate processing, the human operator, has certain abilities and limitations which cannot be changed. But they can be employed to the greatest advantage of the entire process by careful design of the photo-measuring system.

"Since the instrument designer must furnish the user with an effective link between the photo and final data, he must be concerned not only with the internal design of the man-machine process, but must also know the real properties of the photo and the real requirements of the data reduction program. A good photo-measuring instrument should fit consistently into the entire scheme of acquisition, interpretation, measurement, data processing, end use.

"This paper will discuss the conflicts and compromises encountered in measuring instrument design:

1. The photograph itself
2. The measuring instrument's speed, cost, accuracy
3. Visual presentation and its effect on human observers
4. Visual problems of detail, interpreting context, deciding upon coincidence
5. Instrument output values in terms of its subsequent use deriving object parameters from image parameters."

SESSION III
METHODS OF VISUAL ENHANCEMENT
Session Chairman: Paul Pryor, WPAFB

CRITERIA FOR SPECIFYING PROJECTORS FOR THE PHOTOINTERPRETER

J. E. Davis
Aerospace Group
Hughes Aircraft Company
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"A practical approach to specifying and designing large format rear screen projectors for aerial reconnaissance photography is outlined. Unique brightness control methods are discussed in terms of their proper use to keep the interpreter's pupilary diameter at a size to allow maximum visual acuity. Methods for keeping a uniform brightness over the screen for different viewing positions is described. Solutions are outlined for factors contributing to uneven screen brightness such as the observation angle with the principal axis of the diffusion lobe of the screen, system vignetting, and cosine^4 effects. These solutions include the use of larger diameter Fresnel lenses, strategically placed apodizing filters, and a discussion of the Luneburg criteria for condenser lens design.

"Characteristics of rear projection screening materials are discussed in terms of their performance in the projection of high definition (100 to 200 medium contrast lines per millimeter) photographic records. A system for evaluating screening materials by their modulation transfer function is proposed. Measurement of the imagery by moving reticles in the projected field is discussed and the problems associated with obtaining sharp, fine lines on the screen with this type of system are summarized. Various light sources and their effects on interpretation, good and bad, are described. The use of image rotators, both optical and mechanical, as an aid in angular measurement of the imagery is outlined.

"A formula is developed for an empirical formula for determining the minimum magnification of a projector based on the resolution capability of all the elements in the system from film to, and including, the eye is developed. Also a method for designing projection systems using the modulation transfer function of each element, including the eye, is analyzed."

Comments:

The paper as delivered hardly lived up to the expectations generated by the abstract. It was, however, pointed out that the resolution of a viewing screen tends to increase with screen gain, but corner brightness tends to fall off. Also, as surrounding brightness levels increase, the contrast requirements for target areas increase.

The empirical formula developed to describe system resolution is

$$\frac{1}{R_s^{1.7}} = \frac{1}{R_1^{1.7}} + \frac{1}{R_2^{1.7}} + \ldots$$

where R_s = system resolution

R_1, R_2, etc., are resolutions of individual elements in the system such as film, screen lens, and the eye.

DISCREPANCY BETWEEN OBJECTIVE AND PERCEIVED SLANT

Martha J. Guastella
Human Factors Laboratory
U. S. Naval Training Devices Center
Port Washington, New York

"Judgement of perceived position under conditions of darkness and monocular viewing at a 10 foot distance were made of a two-dimensional luminous target set at varying degrees of rotation with respect to the observer. A trapezoid was presented randomly and sequentially at approximately 10 degree intervals throughout 360 degrees rotation.

"Under these reduced viewing conditions the fourteen subjects tended to position the target at a slant regardless of its true orientation. Errors of individual judgements were found to be very small and varied in magnitude as a function of misperception. Results indicate that the angle of rotation of the target is not the stimulus condition for the perception or orientation. While position adjustment follows, in part, the increments in visual angle associated with the horizontal expansion of the target, this relationship breaks down and other changes appear to be the more important cue. The fact that adjustments made under the orderly sequence simulating rotation did not differ from those made under random presentations indicated that memory or set was not a factor in this adjustment."

IMAGE TRANSFORMATION ON THE RETINA

Martha J. Guastella
U. S. Naval Training Devices Center
Port Washington, New York

"The use of a varying picture plane model is presented as a hypothetical construct to extend image transformation of the retina. The hypothetical construct is used as a means for analyzing the changes in retinal stimulation, taking into account changes in three dimensions. A dynamic analysis involving the ratio of vertical and horizontal changes in the boundary of the figure is used to predict the perceptual outcome. Accounting for changes between true and apparent rotary movements, the present theory permits analysis of illustory as well as nonillustory visual experience."

Comments:

The two papers above, taken together, provide a mathematical model to describe certain illustory effects. A specific example of the Ames illusion, in which a rotating trapezoid appears to oscillate back and forth instead, was effectively demonstrated.

A RAPID ACCESS COLOR RECONNAISSANCE SYSTEM

Sondra Wendroth and Edward Yose
Fairchild Space & Defense Systems
Syosset, L. I., New York

"The results in recent research in spectral zonal photography which have resulted in the development of a Spectral Zonal Reconnaissance System are discussed. This research has achieved a practical system based on concepts of abridged spectrophotometry and calorimetry for photographing the 3800 to 9500 Angstrom spectrum. Spectral zonal presentations of terrain having the following characteristics will be shown:

1. Individual black and white spectral zonal image
2. Composite black and white panchromatic image
3. A true color composite image of the terrain
4. A color coded image presentation indicating disturbances to the terrain such as camouflage
5. A color presentation allowing dynamic correction for atmospheric haze, solar illumination and differences in the target spectral reflectance
6. Spatial resolution equal to conventional reconnaissance camera systems along with spectral discrimination
7. Minimized delay between taking photographs and viewing results

"The chromatic accuracies obtainable from color aerial photographs taken using the additive color principle is discussed.

"Additive color aerial photography is obtained by the simultaneous imaging reflected electromagnetic radiation from the terrain through selected filters on a suitable achromatic recording medium. When such photographs are projected through compensating filters, the image is seen in color.

"The accuracy of the color representation of the scene referenced to a given standard is dependent on factors which include: filter-lens-emulsion combination in the taking camera; accuracy with which the characteristic curves of the individual photographs can be controlled in processing; variations in the spectral quality of the scene illuminant; the variable attenuation of the atmosphere.

"The relationship of object color in the scene to image color as viewed by an observer will be presented in terms of C.I.E. chromaticity coordinates.

"Compensations for chromatic inaccuracies in viewing due to the mentioned effects can be partially adjusted for the entire scene by variation of the hue, brightness and saturation of the image. The extent to which this correction can be accomplished will be shown.

"The results of a series of experiments to determine the accuracy of many classes of geographical characteristics are presented. Examples of the chromatic differentiation of conditions of vigor of deciduous foliage as well as certain classes of camouflage will be shown."

Comments:

This paper on spectral zonal photography was well delivered but described little that was new or unique in this field. Experimental photographic camera and display systems of this nature were developed by [redacted] at least as early as 1959, followed by the nine-lens multiband camera, and a four-channel viewer/printer. Of course, "multiband photography," in the form of three-color additive photography, stems from work performed by James Clerk Maxwell near the turn of the century. In recent years a number of industries, government agencies, and universities have become increasingly interested in this type of photography. A very current example is the three-band reconstruction of the color of the surface of the moon provided by photographs from the Surveyor I spacecraft.

STAT

The following abstract appeared in the program but was not delivered:

DISTORTIONS OF VISUAL SPACE

Gerald H. Fisher
Department of Psychology
University of Newcastle upon Tyne
England

"Before psychology emerged as an independent scientific discipline, philosophers, physicists and physiologists became fascinated by some remarkable and dramatic features of a rather unusual set of line drawings. These drawings are composed of patterns of lines and shapes juxtaposed in such a way that their configurations appear to be variously distorted and attenuated. The addition of brackets, flaring in opposite directions, to the ends of two lines of equal length, that they appear to be of unequal lengths; a continuous oblique line, passing across and apparently behind two parallel vertical lines, seems to be discontinuous; while a simple cross in the shape of a plus sign, the arms of which are exactly the same length, appears to be composed of lines differing in length. The spatial distortions seen in these and many other linear and curvilinear figures, have become known as the 'geometrical illusions.'

"There is a good deal of antipathy toward the study of the distortions of visual space. The principal reason for this rests upon the claim that, while spatial distortions are evident in abstract situations, they are not seen when embodied within the concrete conditions of real life. This argument has been considered in experiments embodying new techniques for presentation of illusion figures in abstract and concrete, static and dynamic, and monocular and binocular situations.

"The results of these experiments suggest strongly that spatial distortions are not confined to abstract situations but extend to concrete, real-life conditions, the denotable physical characteristics of which are such as to embody the spatial features of an illusion-type display.

"In the context of the results of these and a variety of other experiments, existing theories relevant to explaining aspects of shape and space perception in general and to spatial distortions in particular, are described and discussed critically. New principles are suggested which appear to extend our understanding of the mechanisms underlying these distortions. It is concluded that no single element can account for illustory-type spatial distortions but rather that, as in the case of a general theory of space perception, a number of complementary and frequently conflicting, perceptual systems are brought into operation and must be invoked in order to explain the characteristic nature of their perception."

SESSION IV
DECISION MAKING FROM IMAGE PRESENTATIONS
Session Chairman: Dr. Shelton MacLeod, RADC

A METHOD FOR RAPID HUMAN DECODING OF DIGITAL DATA RECORDED ON FILM

J. K. Libby
Fairchild Space & Defense Systems
Syossett, L. I., New York

"This paper describes a manual method for rapid human decoding of digital data recorded on film. This method provides visual enhancement of tiny digital data for more effective human decision making.

"The Department of Defense has directed the Army, Navy, Air Force and Marine Corps to use the common reconnaissance mapping data marking system established by MIL-STD-782B (Wep). All existing data marking systems are to be converted to the binary-coded decimal system described in this standard.

"The manual method provides a means for the photointerpreter to perform relatively rapid, yet accurate decoding and recording of the binary coded decimal (BCD) data. The tiny BCD bits are magnified by a rear projection system so they are easily read and provide sufficient spacing for rapid annotation of each character on a specifically designed mask. This mask serves a dual purpose:

1) grouping the data bits functionally for rapid identification and reading under all specified positions of the CMB;
2) providing a medium for recording the data being read which can be reused or kept for record purposes.

"The compact projection system is designed for maximum light transmission so that it can use existing diffused light sources. It is simply placed over the tactical reconnaissance film being viewed on any direct viewing light table."

IMAGE ACCURACY AS RELATED TO DECISION MAKING

Richard Sweeton
Corporate Technology Center
Kollsman Instrument Corporation
Elmhurst, L. I., New York

"The decision maker referring to an image presentation must know the degree of accuracy of the presentation or have blind faith that it is accurate when he makes his decisions. This is particularly important when he is making decisions where an error can result in deaths, as in command control, or in a major economic loss to his company, as in computer-aided management.

"Displayed information is generally referred to a map or chart grid or to a prediction. The decisions then are essentially forced by the displayed data moving off or across a line. If the display is misregistered with the reference line, errors are likely to occur. This misregistration can be inherent to the display equipment, or it can develop while the equipment is being used.

"In building projection display systems for command and control for training, Kollsman has made accuracy analyses and has developed procedures for confirming system accuracy before depending on display. New approaches are now being studied for in-process checks on display accuracy. This paper will cover types of display registration (spot references, line reference, zone references); accuracy analysis techniques; equipment factors affecting accuracy; and approaches to in-process checks on accuracy."

DECISION GUIDELINES FOR IMAGE INTERPRETERS

James M. McKendry and Paul Harrison
HRB - Singer Inc.
State College, Pennsylvania

"A conceptual framework was proposed which summarizes a multitude of specific activities which, when taken collectively, comprise a significant portion of the image interpretation process. Usually, these activities are either informally or formally organized into sequences of behavior, guided by a desire to follow certain general rules.

"In this study, quantitative criterion data, based on user needs, were obtained which permit derivation of clear image interpretation strategies. If followed, the strategies should allow interpreters to maximize the worth of their reports. The data are particularly applicable to the task of interpreting ambiguous or incomplete imagery."

AN APPROACH TO THE EVALUATION OF RECONNAISSANCE SYSTEMS

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Reconnaissance Intelligence Data Handling Branch, USAF
Headquarters Rome ADC (AFSC), Griffiss AFB, New York

"This paper discusses measurement of image interpreter performance as means for assessing techniques associated with proposed improvements in reconnaissance technology (i.e., associated with the collection, display, and processing of reconnaissance imagery). Selected examples of research will be described to illustrate this approach including a discussion of methodology for evaluating the contribution of color imagery.

PROBLEMS IN MEASURING DISPLAY PERFORMANCE

Joseph L. Hallett
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"Visual presentations, commonly called displays, overlap many engineering disciplines. As a result, many different methods for measuring display performance have been developed, depending on the background and experience of the particular agency, company or individuals involved. This paper is intended to highlight the problems of first obtaining a workable definition of the end result desired from a given display, and second, obtaining a workable method for rapid and accurate measurements of the performance of individual components and equipment which must eventually go together and satisfy the user's needs. Typically, the user wants legibility and error-free performance, while the component and system designer is more interested in such parameters as contrast, brightness, color and resolution. To further complicate the problem, the units and measurement techniques differ widely between different engineering disciplines. Deficiencies in measuring equipment further restrict both the user and the display designer from reaching quick and easy conclusions about the performance of a particular display.

The small lighted areas of most displayed data make some form of spot photometer necessary to measure brightness; the monochromatic nature of many displays makes most spot photometer measurements highly questionable unless care has been taken to calibrate the instrument on a standard source having the proper spectral energy distribution. Contrast is considered to be important display parameter, yet the various methods for establishing a known ambient illumination level can give quite different numerical results. The human eye is extremely tolerant of color and brightness changes, yet most display specifications are quite rigid in controlling these parameters. It is hoped that the discussion stimulated by these and other problems will help to establish a climate where coordination of display measuring techniques and standards will be accomplished."

APPENDIX B

VISUAL PROCESSES - ANNOTATED BIBLIOGRAPHY

TABLE OF CONTENTS

B.1 PHYSIOLOGY

1. Yves Le Grand, Light, Color and Vision, London, Chapman and Hall, Ltd., 1957.

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.

2. George Wald, "Eye and Camera," Scientific American, Vol. 183, No. 8, August 1950.

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

Each grain of silver bromide in exposed film blackens completely or not at all; grain made susceptible to development by absorption of one or a few quanta of light. Similarly, cone or rod is excited by light to yield maximal response or none. Absorption of quantum of light by light-sensitive molecule in either structure might convert it into a biologic 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 sensitivity shift toward higher wavelengths in bright light compensate for chromatic aberration of eye, which is greatest in blue and violet. Rods have max. sensitivity about 500 mμ; cones 562. Also fovea and region of retina around it are colored yellow in man, apes and 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 three kinds of responses. Simplest assumption is that three light-sensitive pigments. In chicken and turtle, oil globules in cones are three colors: red, orange, greenish-yellow.

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

3. David H. Hubel, "Visual Cortex of the Brain," Scientific American, Vol. 209, No. 5, November 1963, pp. 54-62.

Transformation of retinal image into perception occurs partly in retina 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: three in retina, one in geniculatebody (pair of cell clusters in brain), two in cortex.

Nerve cells on neurons transmit messages as electrochemical impulses. In a given fiber all impulses have same amplitude; strength of stimulus reflected in frequency (1/2 to 100 m/sec). Fiber of nerve cell contacts 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 and analysis of nerve messages takes place at synapses.

Studies of visual system of cat: record impulses with microelectrodes in incoming and 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 between 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 excitatory and inhibitory impulses at once: responds according to net effect of inputs.

Retinal ganglion cells fire at fairly steady rate even in absence of stimulation. Kuffler: resting discharges of ganglion 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). Turning 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 varied according to place where light struck field, for example, two spots of light on separate parts of an "on" area produced more vigorous "on" response than either spot along; 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 diffusely 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 illumination 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 between 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. Cortical cells do not have concentric receptive fields: many different types with fields different from retinal and 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 respond best to bars, slits, edges, provided that suitably oriented; but not so discriminating as to position of stimulus if properly oriented. Complex cells respond with sustained firing to moving lines.

From preference for specific orientation of stimuli, there 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 activates some of geniculate cells and leads to activation of cortical cells. Each simple cortical cell has specific duties: takes care of one part of retina, responds best to one shape of stimulus and 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.

Complex cortical cells. Respond best to line stimuli and must be oriented to suit cell, but cannot be mapped into antagonistic "on" and "off" regions. For example, in a typical complex cell, a vertical edge evoked response anywhere within receptive field, "on" with light to left, "off" with light to right. When stimulus is removed, without changing orientation, complex cell responds with sustained firing. Continues as moved over substantial retinal area, whereas simple cell only responds to movement as crosses boundary between "on" and "off" regions. These findings can be explained by supposition that a complex cell receives its input from many simple cells.

Simples must have same field orientation and be of same general type, and retinal positions of simple fields must be arranged throughout area occupied by the complex field. This requires enormous degree of cortical organization. Authors found evidence that such organization exists: arrangement of cortical cells with high degree of order. Cortex divided into functional columns of cells extending from surface to white matter. In each column, all cells have same receptive-field orientation (from vertical microelectrode probe). In respects other than orientation cells in a column differ: simple, complex, respond to slits or bars or edges. Receptive fields vary randomly in exact retinal positions, though all same general retinal region. Column is functional unit in which simple cells receive connections from lateral geniculate cells and send projections to complex cells.

Example, if looking at form such as black square on white background: near edge of square will activate particular group of simple cells, which prefer edges with light to left and dark to right and whose fields oriented vertically and so placed that boundary betweeen "on" and "off" regions falls exactly along image of near side of square. Other populations of cells activated by other three edges. Each edge also activates a population of complex cells, but these continue to be activated when eye or form moves. Thus populations of complex cells affected by whole square will be to some extent independent of exact position of image of square on retina.

Visual cortex analyzes enormous amount of information, with each small region of visual field represented over and over in column after column, first for one receptive field orientation and then for another. Cortex rearranges input from lateral geniculate body in a way that makes lines and contours most important stimuli. First step in perceptual generalization results from response of cortical cells to orientation (apart from exact retinal position) of stimulus. Movement also important stimulus factor. Rate and direction must be specified if a cell is to be effectively driven.

If connections suggested by these studies are close to reality, can conclude that at least some parts of brain can be followed relatively easily, without requiring higher math, computers, or knowledge of network theories.

4. W. H. Miller, F. Ratliff, and H. K. Hartline, "How Cells Receive Stimuli", Scientific American, Vol. 205, No. 3, Sept. 1961, pp. 222-238.

In eyes of vertebrates no one has detected impulses in rods and cones. Have been detected in optic nerve, which is composed of fibers of ganglion cells separated from rods and cones by at least one group of nerve cells. In any nerve fiber, impulses same magnitude, form, and speed; variation in intensity of stimulus affects frequency of nerve impulses. Animals decode sensory messages because each type of receptor communicates to higher nerve centers through private set of nerve channels. Stimulation of receptor cells appears to cause a sustained local depolarization of sensory nerve fiber, which generates train of impulses ("generator potentials" at cellular level). 1935 generator potential found in single optic nerve fiber and receptor in compound eye of horseshoe crab Limulus. 1950 demonstrated small steady depolarization in nerve fiber from vertebrate muscle spindle. Superimposed on shifted signal (local potential) was a series of peaks representing individual nerve impulses. In steady state, frequency of impulses depends directly on magnitude of altered potential. Local anesthetic: impulses abolished, potential shift remains. Now abundant evidence that a receptor cell triggers a train of nerve impulses by locally depolarizing the adjacent nerve fiber, its own or that of another cell. With sustained depolarizing current, responds briefly, then accommodates to stimulus. Only in photoreceptors have we any knowledge of how stimulus produces generator potential. In work on Limulus, site of origin of generator potential has not been identified with certainty, nor has activity been detected in axons of retinular cells. In photosensory cells alone, direct experimental evidence (through photochemistry) of initial molecular events in receptor process.

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 rhodopsin corresponds 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 outer 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 repetition 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: 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 and 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.

5. Donald Kennedy, "Inhibition in Visual Systems," Scientific American, Vol. 209, No. 1, July 1963, pp. 122-130.

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 and 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" photosensitivity: 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.

6. L. J. & M. J. Milne, "Electrical Events in Vision," Scientific American, Vol. 195, No. 6, Dec. 1956, pp. 113-122.

Information sent by eye to brain consists of electrical impulses arising from eye's absorption of elementary quanta of light. In 19th century it was demonstrated, by making electrical connection between outside eyeball and retina, that eye, rather than reaction in brain, was responsible for ratio of response to intensity of stimulus: size of voltage jump is proportional to log of intensity, that is, to double electrical effect, light energy must increase ten teimes (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 it has been possible to record without removing the eye, that is, on human subjects.

Adaptation. Eye collects light as length of exposure 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 of evolution from aquatic life. Cones are comparatively blind to red, thus can use red for warning lights, instrument panels, etc. without losing dark adaptation.

Threshold of visual response. Experiments 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.

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

7. Derek H. Fender, "Control Mechanisms of the Eye," Scientific American, Vol. 211, No. 1, July 1964, pp. 24-33.

Article considers eye as servomechanism, or device that controls variable physical quantity by comparing its actual value with a desired reference 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 corresponding areas of two foveas. Each of three pairs of rotating muscles receives signals proportional to the displacement 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. Accommodation 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 and accommodation mechanisms are separate, but cross-linked: information derived by one is fed to the other; for example, information 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 eyelids out of way when looking 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 movement 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 and lock onto it. 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 no longer in fovea) is unaffected by drugs and is presumably retinal.

Bipolar cells, amacrine cells, and ganglia in retina seem capable of more than merely passing light signals on to brain: retinas discriminate and filter information in lower animals, and 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.

8. Roy M. Pritchard, "Stabilized Images on the Retina," Scientific American, Vol. 204, No. 6, June 1961, pp. 72-78.

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 1/2 frequency of a single cone receptor. This motion plays significant role in sensory functions: when an image stabilized, it 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 experiments 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. Simples figures such as lines vanish rapidly and reappear as complete images. Complex images may vanish in fragments, parts fading independently. Time of persistence of image is function of complexity.

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. Continuity 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. 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 amplitude, frequency and form of movement necessary to sustain or regenerate a particular color.

9. L. A. Riggs and S. U. Tulunay, "Visual Effects of Varying the Extent of Compensation for Eye Movements," JOSA, Vol. 49, No. 8, Aug. 1959, pp. 741-745.

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 disappearance of image motion introduced in amount 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, and 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 percent 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 represent 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.

10. Hugh Davson, ed., The Eye, Vol. 2: The Visual Process, New York, London, Academic Press, 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 1-diopter lens has a focal length of 1 meter, a 10-diopter lens, 1 of 0.1 meter, and so on, diopter being the reciprocal of the focal length in meters.)

Behind anterior chamber is lens, a double-convex 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 mμ is about 1/2 diopter too strong for perfect focusing of 800 mμ and about 2 diopters too weak for perfect focusing of 400 mμ. This chromatic aberration becomes worse for shorter wavelengths. Thus axial aberration at 300 mμ is 6-7 diopters. Inability to focus light of w.l. 300 mμ and lower limits use of these wavelengths for vision: refracting eye (unlike compound eye) is only feebly sensitive to these radiations.

B.2 DUPLICITY (LUMINOUS EFFICIENCY)

11. Davson, op. cit.

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 illumination level of dark night, fovea is blind, only peripheral vision operative, acuity much lower than in daylight and 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 (for example, in dim light, blue objects look very much brighter than red). Because of different spectral sensitivity of rods and 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 relative spectral composition of two lights the 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 reflect light of different spectral composition, so color vision on dark night should not be physical impossibility. Example: color photos in astronomy: study spectral composition of light emitted by celestial bodies, "color" of which is never directly seen.

At very low illumination, eye becomes incapable of distinguishing between lights of different spectral composition, only differences seen being those of brightness. Light too faint to stimulate cones; rod system only functioning; this system incapable of responding in qualitatively different manner to light of different wavelengths.

Why has rod system not developed powers of wavelength discrimination? Probably connected with fact that visual acuity becomes so poor on dark night that wavelength discrimination would be of no biological 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 distinguished, color vision loses its point. Also, quantum fluctuations would set limit to accuracy with which spectral 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 numbers of quanta acting on spectrally selective cone mechanisms.

Luminous efficiency of light ray entering 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 estimated 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 efficiency 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 stimulated for peripheral than for central entry. Thus when peripheral entry used, provided field luminance properly adjusted, cones are not stimulated at all, or stimulation 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 and cones in many phenomena.

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

In extrafoveal test areas, large difference between curves at high and 0 field luminance. Those for bright field approximate in shape to foveal curves; those for dark-adapted eye have almost flattened out, so that luminous efficiency of light pencil becomes almost independent of point of entry through pupil. Foveal curves nearly same for high and 0 conditioning luminance, that is, pronounced directional sensitivity for both directions.

Weale (1961): varying thicknesses of eye lens, which contains yellow pigment, may generate for light of short wavelength a difference between the Stiles-Crawford effects 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 directional sensitivity at short wavelength.

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 be isolated 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 peripheral vision, using natural pupil, there is an intermediate range of intensities where rods and peripheral cones both appear to be active, and where luminous efficiency shifts from rod to cone curve as intensity increased.

Range of low luminance levels ("scotopic") refers largely to rod function, intermediate ("mesopic") to combinations of rod and cone function. Photopic range (daylight) 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 more than 1 to 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. Absorbs max. in blue-green, where also max. sensitivity; very little in deep red, where rod sensitivity is also low.

Absorption spectrum of human rhodopsin has been measured in vitro on extracts. For purely optical reasons, shape of absorption spectrum of a substance varies with optical density (log to base 10 of ratio of intensity of incident light by intensity transmitted) of the absorbing layer. Close correspondence with rod quantum sensitivity at retinal level. This correspondence sufficiently good to support theory of rod sensitivity curve. This was very important when no pigments yet extracted from human cones. (See influence of wavelength on uncertainty of seeing.) Curves pp. 75-76, max. about 500 mμ.

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

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 efficiency of radiation must always correspond either to the scotopic or to the photopic function (p. 88).

B.3 ADAPTATION AND AFTERIMAGES

12. Davson, op. cit.

Page 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 experiment, 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 and 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, especially the cone-rod transition time, remains very similar from one subject to another. Individual final rod thresholds cover range of 1 log unit, that is, 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 illumination may be required.

When most of rhodopsin has been bleached in living human eye, it takes about 1/2 hour to regenerate completely. Cone pigment takes only 7 min. to regenerate. Some important link between regeneration 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. Correlation may exist but fail to be detected because of psychological variations.

Afterimages are the more obvious of the subjective phenomena which occur when eye has been submitted to light stimuli. If eyes closed after looking fixedly at light source or illuminated object, there is seen patch, size and shape of which related to that of source: few seconds to several minutes, or if very intense primary stimulus, may last for weeks. If looking at uniformly illuminated surface instead of closing eyes, afterimages are seen which are darker than the surface ("negative afterimages").

Modes of appearance of afterimages do not obey hard and fast rules. If colored source, positive afterimage may be same color as source, negative 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 increases. 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 equivalent amounts of plane-polarized and unpolarized lights produce indistinguishable afterimages. A fixed amount of light, whether delivered during 0.02 sec or distributed over 2 sec, always produces same afterimage, even though subjective effects of stimulus itself are very different. This seems to suggest that the change responsible for afterimages is primarily a photochemical one.

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

Troxler phenomenon: progressive dimming and disappearance of illuminated field, the image of which kept steadily on the retina. Generally occurs with artificial stabilization of retinal images. In periphery, especially 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^{o} field at 20^{o} 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 reappeared 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 absolute 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.

13. G. S. Brindley, "Afterimages," Scientific American, Vol. 209, No. 4, Oct. 1960, pp. 84-93.

Negative afterimages (seen against white background) presumably due to insensitivity or "fatigue" of some part of the visual system, caused by 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 reception of primary colors can be fatigued, and can show persistent excitation, independently of each other. At least part of fatigue responsible for negative afterimages occurs in eye and not in brain (experienced 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. Negative 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/$m^2 \times$ sec) were discriminated more readily by afterimages than immediate sensations. Fits hypothesis of photochem origin. Total information regarding light intensity capable of being received by pigments of retina is greater than the nerve circuitry of visual pathway can transmit instantaneously; but can transmit additional information 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 possess 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.

Chemical 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 retinene 1 as diffusible product. But afterimage experienced indicates that different diffusible products are liberated by light acting on chlorolabe and erythrolabe; thus either not retinene 1 derivatives, or diffusible substances responsible for afterimages are secondary products.

B.4 THRESHOLD

14. LeGrand, op. cit.

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 (pp. 271-272).

15. Davson, op. cit.

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 biological 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 subjects 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 subjects 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 illumination 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 amount of radiant energy that can cause a visual sensation.

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 subjects who never reported blanks "seen" gave 55% threshold values between 85 and 114 quanta.

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

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

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

Assuming that uncertainty of seeing entirely determined by quantum fluctuations: if probability of one subject seeing stimulus is 1/2, probability that one of two will see (with one eye each) is 3/4.

Similar results obtained for two eyes of one subject 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 physical 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.

Because of quantum properties of light, actual physical light stimulus absorbed by retinal receptors varies from one trial to another, even when all experimental conditions held constant. Smaller number of quanta, more important the fluctuations.

Quantum theory states that any emission or absorption of radiation takes place in a number of individual discrete events, in each of which a single quantum exchanged. When studying quantum events we deal only with probabilities, such as probability of absorption of a quantum by a given retinal receptor. Under constant experimental conditions the <u>mean</u> number of quanta absorbed by the rod, in many trials will be constant. But actual number will vary and is impossible to predict for any given trial.

Amount of light of 507 mμ equivalent to above amounts of white light can be calculated from scotopic luminous efficiency function. Direct experimental comparison with spectral band in green and 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 1/4 minute exposure; 99.7% fail to absorb even a single quantum and are totally unaffected by stimulus. The large field is probably seen when a few quanta have been absorbed in the receptive field of an optic nerve fiber within summation time of this retinal functional unit; or stimulation of more than one such unit may be required for threshold vision. Quantum fluctuations 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 absorb 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; subject cannot distinguish between large luminous circle and each of component halves presented separately in flashes.

Average absolute threshold for effectively point source emitting white light and observations in extrafoveal vision with natural pupil, or order of 4×10^{-9} lumen/m^2. Thus a source of one candela could be seen at distance of order of 16 km if intervening medium perfectly transparent. Actual determinations have given values ranging between 8×10^{-10} and 11×10^{-9} lumen/m^2.

For flashes less than 0.1 sec for small fields, threshold energy content of flash becomes minimal and independent of flash duration. According to Ricco's Law a similar state of affairs exists for angular area of test field. Thus small brief flashes of light of 507 mμ, presented with help of fixation point in most sensitive region of dark-adapted retina, make possible to determine smallest quantity of radiant energy which must enter eye to make light source visible. Experiment by Hecht: results for 7 subjects 54-148 quanta of light for flashes seen in 60% of trials. For three subjects, five experiments, 55% frequency of seening 9 - 143 quanta (safer values). These three subjects did not report as "seen" the blanks which were introduced in random series of genuine flashes.

If one rod were incapable of being stimulated by one quantum, there would be no stimulation in 90% of flashes, whereas only 45% fail to be seen. Therefore a retinal rod is capable of stimulation by absorption of a single quantum. But absorption of quantum does not necessarily cause effective stimulation in rod. Difference between effect of absorption of one and two quanta is not known. One quantum is not sufficient to make human subject see light stimulus. If area or duration of light stimulus is increased beyond certain limits, mean total amount of light required for threshold vision begins to increase considerably. This should not be so on hypothesis that one quantum acting on rod is sufficient for seeing.

Interpretation of absolute threshold measurements in fovea much more complex than in case of rod vision, since several cone mechanisms whose properties much less well known than those of rhodopsin. Foveal region, though small, heterogeneous in its properties.

Stiles 1937 and Pirenne 1956: limit of perception of point source of white light corresponds to illumination at eye of about 10^{-7} photopic lumen per square meter for foveal vision. Light flux entering a 50 mm^2 pupil is then 5×10^{-12} lumen. Since measurements refer to cone vision, correction for Stiles-Crawford effect is applicable; effective pupil area calculated to be 24.6 mm^2. Thus effective light flux which would be required for a small central pupil is only 2.5×10^{-12} lumen. This would be equivalent to about 10,000 quanta (555 mμ) per sec. These results refer to long exposures of the light source.

For an effectively point source the threshold values are higher for cone than for rod vision, difference being greater for steady source than for brief flash on account of greater range of temporal summation of rod.

For absolute parafoveal threshold, slope of frequency-of-seeing curve almost same from 430 to 700 mμ. This confirms interpretation of rod sensitivity curve in chapter 4. For central entry, in which case cones are stimulated at long wavelengths, slope increases beyond 550 mμ, reaching value of about 25 at 700 mμ.

Pinegin (1958) found for given retinal position (in periphery) and field size, slope of curve independent of wavelength. Riezler et al.,(1954) found steeper curves for long and short wavelengths than for 505 mμ. Problem seems worth investigating further with technique used by Flamant and Stiles (1948).

Pinegin obtained steeper frequency-of-seeing curves for foveal than for peripheral vision. Apparent number of acting quanta varied with field size but not with wavelength.

B.5 PERCEPTION

16. John C. Eccles, "The Physiology of Imagination," Scientific American, Vol. 199, No. 3, Sept. 1958, pp. 135-146.

Electric 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, including summation of impulses, crossing 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 maintain 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 relay high voltage: many neurons activated in phase; negligibly small potential of fast waves suggests intense and finely patterned activity.

Each type of sensory receptor activates neurons in narrow vertical columns of cortex. Information from any sense organ must be capable of integration with that from any other. Electric stimuli applied to sensory zones of cortex evoke only chaotic sensations, since they excite tens of thousands 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 individual neuron.

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

Different image-forming process involved in creative imagination. Prerequisites for creating activity of subconscious: in neuronal network must be enormous development of highly complex engrams (permanent 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 and 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 and transcends existing patterns, may expect intensification of activity in cortex which brings pattern to conscious attention.

17. Frank Barron, "The Psychology of Imagination," Scientific American, Vol. 199, No. 3, Sept. 1958, pp. 150-156.

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 and to preference for asymmetry. Creative people not "psychologically healthy" by ordinary definitions (stability, friendliness, social responsibility). Need another definition. Creative people, 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 and value accurate observations.
Often express part-truths in order to stress the usually unobserved.
Independent in thought and will suffer pain to testify correctly.
Greater brain capacity; can cope with more ideas at once and make richer synthesis.
More vigorous: large fund of psychic and physical energy.
Universe more complex and lead more complex lives.
More contact with life of unconscious: fantasy, reverie, imagination.
Broad and flexible awareness of selves.

18. R. L. Fantz, "Origin of Form Perception," Scientific American, Vol. 204, No. 5, May 1961, p. 66.

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 a result of learning process, since appears at all ages. Acuity of vision is poor at birth and 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 development 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 and 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 and spatial orientation demonstrates innate knowledge of environment.

19. N. Gattman and H. I, Kalish, "Experiments in Discrimination," Scientific American, Vol. 198, No. 1, Jan. 1958, pp. 77-82.

Stimulus generalization: a learned response to specific stimulus carries over to whole class of similar stimuli. Hovland and 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 discrimination (between two wavelengths) enhanced response to new range; that is, shifted peak response away from the negative stimulus. As response to conditioned stimulus increased, resp. to associated stimuli increased in same ratio.

Stresses may heighten generalization and extend its range, that is, show exaggerated reactions to stimuli which ordinarily would evoke no response. In extreme case would react indiscriminately to virtually all stimuli in environment.

20. Ulric Neissen, "Visual Search," Scientific American, Vol. 210, No. 6, June 1964, pp. 94-102.

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 and digested by more elementary ones. Experiments with visual search at the boundary between perception and 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 that letters not sought, and cannot remember them when changed.

Multiple search does not take more time, so extra information must be flowing in parallel rather than in increased depth. Many processes can be carried out together (in 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 number of different targets that can terminate it successfully. Cognitive operations involved are more than simply a search for component letters (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 target is important, for example, the letter Z is quickly found among round letters, but only slowly among angular ones.

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

21. Austin H. Riesen, "Arrested Vision," Scientific American, July 1950.

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

22. Brian B. Boycott, "Learning in the Octopus," Scientific American, Vol. 212, No. 3, March 1965, pp. 42-50.

Karl Lashley studied cerebral cortex of mammals. Concluded that in org of a memory, involvement of specific groups of nerve cells is not as important as the total number of nerve cells available for organization. At least in the octopus's vertical lobe and mammalian cerebral cortex, memory is everywhere and nowhere in particular (relation between amount of vertical lobe left intact and 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 and visual centers developed from a primitive taste-and-bite reflex mechanism. More indirect relation between change in environment 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 environment 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."

23. Eckhard H. Hess, "Attitude and Pupil Size," Scientific American, Vol. 212, No. 4, April 1965, pp. 46-54.

When shown interesting or attractive pictures, pupils of eyes dilate. Response is a measure of interest, emotion, thought processes and 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).

24. W. C. H. Prentice, "Aftereffects in Perception," Scientific American, Vol. 206, No. 1, Jan. 1962, pp. 44-49.

Experiments with reversible figures: cannot maintain orientation of outlined cube or octagon with alternating dark and light sections. Something connected with initial way of seeing the figure becomes satiated. First demonstrated through classical psychological methods, have 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 and 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 and tilting of straight lines -- could not be explained as normalization. Kohler: same mechanism "normalization" and reversal of experimental figures.

Figural aftereffects occur in depth as well as plane. Kohler proposed: when impulses set up a sensory stimulus reaching 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 and 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 and will no longer react as it did initially: object appears distorted or displaced.

Simple to demonstrate that brain, not retina, is responsible for development of figural aftereffects.

Even after Kohler had shown relevance of direct currents to psychological findings, psychologists and physiologists continued to try to explain without recourse to direct currents: proposed complex models of a brain built with insulated pathways. 1946-52 Kohler and 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 response to stimulation and do build up resistance to their own passage by changing electrical properties of cortical tissue. Originally deduced from observation 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 establishing 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 staring at fixed objects). 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.

25. R. M. Pritchard, W. Heron and D. O. Hebb, "Visual Perception Approached by the Method of Stabilized Images," Canadian Journal of Psychology, Vol. 14, No. 2, pp. 67-77.

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

Meaningful 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 psychology; of functioning of whole as perceptual entity; of groups as entities; of similarity and continuity 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 syntheses of simpler ones, though also function as genuine single entities.

26. Davson, op. cit.

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.

B.6 PERCEPTION - STEREO

27. Bela Julesz, "Texture and Visual Perception," Scientific American, Vol. 212, No. 2, Feb. 1965, pp. 38-48.

Studied extent to which one can perceive differences in visual patterns when 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 surface 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?) Experiment showed that simple statistical measurements of brightness not adequate to describe perceptual performance. Discrimination of texture involves a kind of preprocessing: neighboring points with similar brightness values are perceived as forming clusters of lines --"Connectivity detection." Texture discrimination is really based on relatively simple statistics of these clusters.

Spontaneous discrimination occurs even though two fields have same average tonal quality, because granularity of fields is different. Nonspontaneous discrimination: 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 of dark and light. Level of slicing can 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 distinguished from a blue-green, but red-green harder to distinguish from blue-yellow. Dots of nonadjacent hue (red-green, blue-yellow) do not form clusters.

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 discrimination depends on properties of clusters. Cluster detection seems to be primitive and general process (frogs and 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 illustration 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 onto the two retinas are first monocularly recognized and then matched. Monocular recognition 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 psychology, 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 surrounding. Per G. psych. square (having good G.) would be perceived.

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 discrimination 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 information in stereo aerial photos. Connectivity detection is basic to both visual tasks, and is more primitive process than form recognition.

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. Probably 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. (One wonders 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.

28. Eckhard H. Hess, "Shadows and Depth Perception," Scientific American, Vol. 204, No. 3, March 1961, pp. 138-148.

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 coinciding with angle at which picture tilted. If picture in positions beyond 90° left or right of upright, most saw it in intaglio but light source 180° 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.

29. Ross H. Day, Brown University, Letter to Editor, Scientific American, Vol. 205, No. 3, Sept. 1961.

Criticism of Ohwaki (Sci. Am, April 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.

B.7 COLOR

30. W. A. H. Rushton, "Visual Pigments in Man," Scientific American, Vol. 207, No. 5, Nov. 1962, pp. 120-132.

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. Experimental setup uses purple wedge to add the amount 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 and is 90% complete in 15 minutes.

Field adaptation (quick change of sensitivity to large variable field, such as cloudy sky), not dependent on amount 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 and 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 experimented with two superimposed images made on b/w film through different filters; appeared 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 three 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.

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

Experiment 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 and green only.

31. E. F. MacNichol, Jr., "Retinal Mechanisms of Color Vision," Vision Research, Vol. 4, No. 1/2, June 1964, pp. 119-133.

Entire span of spectral colors can be matched by mixtures of lights of any three 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 three primary colors, especially 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 between light entering normally through pupil and light entering from behind through sclera.

Simplest way to distinguish between single- and multireceptor hypotheses is to measure absorption or action spectra of photopigments in situ in single receptors. Author and 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 and 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 and conduction in vertebrate photoreceptors is that very little known about it and it presents a real challenge to investigators. Color-related electrical activity has been found (S-potentials) in fish retinae.

C-responses in fish retinae appear to be signs of definite color discrimination 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-response 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 and 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 and man are not likely to differ very greatly.

32. Davson, op. cit.

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 phenomena 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 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).

Spectrum consists of continuous range of colors and limits given (on p. 224) are only approximate. Different observers give different names to monochromatic lights: for example, 500 mμ may be called blue by one observer and green by another. Ends of spectrum not clearly defined; intense radiation of w.l. greater than 700 mμ 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 mμ.

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

Dominant wavelength and colorimetric purity of a stimulus together define its chromaticity, that is, its color quality without reference to brightness. Two colors 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 three 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 three primaries.

Discrimination. In practice, experimental work has been largely confined to intensity discrimination for lights of similar spectral composition, and chromaticity discrimination for lights of equal intensity. Least perceptible difference between 2 lights depends on number of factors, such as field size, intensity, and criterion adopted for discrimination.

Chromaticity discrimination depends on w.l. values. Near limits of spectrum, especially in deep red, large differences in w.l. make no perceptible difference to color of light; near center of visible spectrum, w.l. difference of as little as 1 mμ can be detected. Best in blue-green and orange-yellow, with secondary minimum in violet-blue (curve p. 275).

Near ends of spectrum, where w.l. discrimination least accurate, relatively small change in purity (add mixture of white light with adjustment of luminosity) can be detected, whereas in green, where w.l. discrimination is good, larger addition of white light needed before change in purity detected.

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

Low intensities. At very low intensities, color discrimination becomes poor and only a few shades can be distinguished. For many colored lights, including spectral lights, there is no color sensation at all even at intensities well above threshold for perception of light. Interval between threshold of light perception and level at which color can be recognized is photochromatic interval. This interval must always be defined with reference to the conditions of viewing. When light seen in brief flashes of near threshold intensity, color recognition 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 stimulate a color mechanism, and if difference in sensitivity between two mechanisms is not very great at the wavelength used, the "wrong" mechanism may by chance be more strongly stimulated than the "right" one.

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

Contrast effects. After adaptation to colored light, white light appears to have hue complementary to adapting light. Successive contrast, due to adaptation of mechanism 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 adjacent colors. When whole scene illuminated by colored light, tendency to ignore the general coloration and "correct" apparent colors of objects. Land experiments depend on combination of "correcting" effect with simultaneous contrast. Photos taken through red and green filters projected on screen using red and white light. General reddening of image largely unnoticed, and parts of screen lit only by white light (corresponding to green and 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.

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 response 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.

33. George Wald, "The Receptors of Human Color Vision," Science, Vol. 145, No. 3636, Sept. 4, 1964, pp. 1007-1017.

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

Experiments 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. Sensitivity throughout spectrum measured in dark-adapted eye. Then one type of receptor selectively adapted to colored light, and redetermination of visual thresholds throughout spectrum revealed spectral sensitivity of other type of receptor. For example, with eye continuously adapted to red light, spectral sensitivity 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 pigment. (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 spectral sensitivity with color of adapting light.)

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

When fovea continuously adapted to bright yellow light, spectral sensitivity 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 and may be too much to expect absolute isolations.

Curves corrected to give spectral sensitivity at level of cones, that is, eliminate distortion from filtering action of yellow structures, max at 430, 540, 575 mμ. Unlike corneal sensitivity curves, corrected curves for two subjects are invariant.

Ocular and macular absorptions. Spectral 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 amount 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 mμ red-receptor accounts entirely for total sensitivity and hue discrimination ceases. If blue- and green-sensitive cones contained red-sensitive pigment they should still function at long wavelengths. Yellow lights used to isolate spectral sensitivity of blue-receptor cause so little adaptation in violet that seems unlikely that blue-sensitive cones contain appreciable amounts of other pigments. Possibility still remains that red-sensitive cones contain mixtures of pigments.

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

<u>Color blindness</u>. (discussion p. 1015 ff.) Color blindness includes not three but four main types, and indeed two different kinds of "deuteranope." One kind lacks green-sensitive pigment and is literally green-blind; other has all three pigments in normal proportions but 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 three 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 and evoke yellow sensation.

34. T. N. Cornsweet, H. Fowler, R. G. Rabedeau, R. E. Whalen, and D. R. Williams, "Changes in the Perceived Color of Very Bright Stimuli," <u>Science</u>, Vol. 128, No. 3329, Oct. 17, 1958, pp. 898-899.

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

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

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

35. Harry Helson, "Some Factors and Implications of Color Constancy," <u>JOSA</u>, Vol. 33, No. 10, Oct. 1943, pp. 555-567.

<u>Colors and forms tend within limits to remain constant</u> in spite of change in illumination and orientation. Problem of color constancy involves not one but many aspects of vision including spatial functions of eye. However, nothing like complete preservation of all color dimensions is found under changing conditions: at best <u>only</u> one or two dimensions remain stable while others change. Surface colors approximate various degrees of constancy while colors seen through aperture maintain closer correspondence with actual stimulus impinging on retina. But aperture colors are no less subject to influence from the aperture screen than surface colors to surroundings.

Animals below man show constancy tendencies as strong as man. Higher psychological functions are, therefore, not involved.

Limits of compensation. Radical change in composition of illumination from daylight (e.g., spectrally homogeneous light) greatly alters relations between 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 increasing distance. Once limits of compensation reached, color changes from common experience are many and baffling.

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

Author regards visual mechanism as unitary mechanism with extraordinary adaptability of function.

Contrast is establishment of gradients, not with respect to reflectances of contiguous surfaces, but with respect to adaptation level which tends to be intermediate between these reflectances. Color compensation occurs for different reasons, but springing from a single source.

Colors also have inherent spatial properties, inseparable from contour and boundary effects and just as important for organization 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, is too early 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 approximate color constancy, thus aids in the production of a stable visual world, not only through preservation of color as such but just as much through preservation of spatial organization which is largely due to the color processes of the eye.

36. Edwin H. Land, "Experiments in Color Vision," Scientific American, Vol. 200, No. 5, May 1959, pp. 84-99.

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 transparencies are illuminated with practically any pair of wavelengths, and images are superimposed, colored images are obtained. If sending 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, distributed 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 minimum separation between the long-record wavelength and the short. Minimum is different for different parts of spectrum, but is astonishingly small. Any pair of wavelengths far enough apart will produce grays and white plus gamut of colors extending well beyond that expected classically from the stimulating wavelengths, including 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.

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 available light is the 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 produce full color, position of colors on graph remains same.

Colors in a natural image are determined by relative balance of long and short wavelengths over entire scene, assuming that relationship changes in somewhat random way from point to point. Within broad limits, actual values of wavelengths makes no difference, nor does overall available 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 - for example, 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 and shorter wavelengths, must establish a balance point or fulcrum on one side of which all wavelengths are taken as long and on other side as short. In ordinary sunlight world fulcrum appears to be at 588 mμ ("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.

37. Deane B. Judd, "Appraisal of Land's Work on Two-Primary Color Projections," JOSA, Vol. 50, No. 3, March 1960, pp. 254-268.

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 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 nobody has noticed before 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 and 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 information in the long- and middle-wave records is similar to the old disproved hypothesis of the constancy of object-color perceptions regardless of color and amount of illumination.

Color-constancy hypothesis really states that it is hard to fool an observer even though incomplete information 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 satisfactory 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. He 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 object-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 portions of the scene conform to the relation $\log C_1 = a \log C_2 + b$, 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 toascribe 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 afflicting current three-primary color processes.

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 that ascribed 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.

38. Hans Wallach, "Perception of Neutral Colors," Scientific American, Vol. 208, No. 1, Jan. 1963, pp. 107-116.

Lightness and darkness are properties of surfaces (not of light). Amount 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 therefore an ambiguous cue to its reflectance or "actual" color. But perceived neutral colors are usually in good agreement with the reflectance of the surface; for example, 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 incomplete.

One variable, the intensity of reflected light, depends on both incident illumination and reflectance of surface. Experiment 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 illumination 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. Special case of reduced contact: intensity gradient replacing sharp border between areas of different intensities. When intensity difference becomes greater than 4 to 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 processes: one, which causes luminousness, directly dependent on intensity of stimulation and state of adaptation of eye; second, which produces the opague colors, is an interaction -- area of retina that receives higher intensity of stimulation induces sensation of gray or black in neighboring region of lower intensity, with particular color roughly dependent on ratio of intensities.

Experiments demonstrate that lightness of chromatic (as well as neutral) colors depends on relation between intensities of stimulation of different regions. Appearance of disk of chromatic light varies, for example, 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 seen through hole in screen at chromatic surface beyond it: surface appears like transparent chromatic film stretched across hole. Raising illumination on screen transforms "film" into a surface color, like piece of colored paper attached toscreen.

39. Alphonse Chapanis, "Color Names for Color Space," American Scientist, Vol. 53, No. 3, Sept. 1965, pp. 327-346.

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 to 165 steps in saturation). In absolute judgments, individuals can only name 12 to 13 colors without appreciable error. Observers are internally consistent, that is, repeat their own judgments accurately, but differences between individuals disconcertingly large, for example, yellowish-green to one is bluish-green to another.

Literary and 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: There are 45 different color names for which selections should not overlap. But 18 percent of color chips were never selected in experiment; theoretically 45 only covers about 82 percent of Munsell color space. Total number of different color names probably 52 to 55. Note that results might have been different if experiment conducted in British, English, or French (learning important).

40. Reports by Medical Research Laboratory, U. S. Naval Submarine Base, New London, Conn.

________, "Preliminary Report on Color Vision Testing," Color Vision Report No. 1, Sept. 12, 1942, AD 622 180.

C. W. Shilling, "Report on Trial of Royal Canadian Navy Color Vision Lantern in Comparison with Other Tests of Color Vision," Color Vision Report No. 2, 18 January 1943 (Reprinted May 1951) AD 622 181.

D. Farnsworth and J. D. Reed, "A Survey of Methods Used in Administering Pseudo-Isochromatic Test Plates for Color Vision," Color Vision Report No. 3, 6 November 1943 (Reprinted January 1950) AD 622 183.

D. Farnsworth, J. D. Reed and C. W. Shilling, "The Effects of Certain Illuminants on Scores Made on Pseudo-Isochromatic Tests," Color Vision Report No. 4, 22 November 1943 (Reprinted December 1948) AD 622 185.

D. Farnsworth and J. D. Reed, "The Effect of Changing the Illumination on the Colors in Pseudo-Isochromatic Plates," Color Vision Report No. 5, 3 January 1944, AD 622 220.

F. L. Dimmick, "The Psychological Dimensions of Color," Report No. 431, 1 June 1964, AD 612 551.

M. H. Siegel, "Discrimination of Color: IV, Sensitivity as a Function of Spectral Wavelength," Report No. 436, 31 July 1964, AD 611 725.

41. Reports by U. S. Naval Submarine Medical Center, Submarine Base, Groton, Conn.

Whitman Richards and Saul M. Luris, "Color Mixture Functions at Low Luminance Levels," Report No. 439, 27 October 1964, AD 618 590.

M. M. Connors and M. H. Siegel, "Differential Color Sensitivity in the Purple Region," Report No. 445, January 1965, AD 618 592.

S. Weissman and J. S. Kinneg, "Relative Yellow-Blue Sensitivity as a Function of Retinal Position and Luminance Level," Report No. 447, 26 February 1965, AD 618 594.

B.8 ACUITY

42. Davson, op. cit.

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 illuminated 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 between retinal stimulation corresponding to gap and that due to other parts of the object itself.

In case of grating consisting of parallel black bars, it is possible to produce "deterioration" of image by using a grating in which bars half as wide as before, but with the 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 illumination 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 adjacent cones receiving blurred images of black and bright bars, but anatomical separation between the cones. Maximum acuity must be reached when all the single-cone units are active.

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

In acuity experiments, subjective observations showed that more and more central parts of retina used as luminance increased. Acuity values up to about 1/8 obtained with peripheral regions of decreasing eccentricity; between 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.

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 subjective 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. One 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 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 between luminance and 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.

B.9 FLICKER

43. Davson, op. cit.

Flickering appearance of a light source which extinguished at regular brief intervals disappears when number of extinctions per second becomes large enough. Critical fusion frequency (number of complete cycles of light and darkness per second) lowest frequency 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 second, presented in periphery while fixation maintained, field looks white shaded with violet. When flicker suddenly changed to steady illumination, 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 and psychological factors.

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

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

Binocular flicker. When both eyes stimulated together, c.f.f. is higher for flickering fields which are in phase than for those out of phase, but difference is not larger. 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 binocular stimulation, 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 and Hart (1960) conclude that binocular response to flicker involves some kind of facilitation between two monocular responses, which takes place at a neural level beyond the chiasma (intersection of optic nerves).

44. Vernon E. Carter, "Image and Cue Enhancement Through the Use of Moving or Flickering Presentations, an Annotated Bibliography," Northrop Nortronics NSS Report No. 2697, 15 August 1963.

45. H. E. Henkes and L. H. van der Tweel, eds, Flicker: Proceedings of Symposium on Physiology and Clinical Electroretinography, Sept. 1963, 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 recording of signals from color receptors. In either case the ERG response 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 arguments for separate brightness and color systems: fact that color flicker and brightness flicker fuse at very different frequencies. If two colors alternated and intensities properly adjusted, may be made to fuse at rate under 20 flashes/sec. This suggests that color mehcnaisms may respond poorly to fast flicker. Le Grand and Geblewicz 1937 found that colored field presented extra-foveally and 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 mechanisms, on basis of different frequencies of fusing, seem to be non seq.)

Article by P. L. Walraven and 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.

B.10 FATIGUE

46. Davson, op. cit.

Experiments with large field and long exposures give steep frequency-of-seeing curves and 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 biological 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 1 to 2, whereas observed range is of order of 1 to 10.

Biological variations become combined in complicated manner with quantum fluctuations and with possible physiological complications; cannot be studied in isolation. Non-independence of successive responses to flashes indicates that biological variations do occur in some experiments; purely quantum fluctuations would be random and lead to independence in successive trials.

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

47. Woodburn Heron, "Pathology of Boredom," Scientific American, Vol. 196, No. 1, January 1957, pp. 52-56.

Research by Mackworth on radar operations on antisubmarine patrol to find out why they 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. Hallucinations have also been reported in experiments where subjects exposed for long periods to blank visual fields of flickering light. Hallucinations began with simple forms and 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. Sensory stimuli in addition to specific functions, maintain arousal, but lose power to do so if they are restricted to repeated stimulation in unchanging environment.

48. W. Heron, B. K. Doane and T. H. Scott, "Visual Disturbances After Prolonged Perceptual Isolation," Canadian Journal of Psychology, Vol. 10, No. 1, March 1956, pp. 13-18.

Apparent movement of objects, distortion of shapes, intensification of colors. Hallucinations continued when closed eyes or replaced goggles. Effects observed after isolation are not due merely to forgetting or perceptual habits. 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.

49. W. H. Bexton, W. Heron and T. H. Scott, "Effects of Decreased Variation in Sensory Environment," Canadian Journal of Psychology, Vol. 8, No. 2, June 1954, pp. 70-76.

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

50. Roland H. Moore and Wendell E. Bryan, "The Practical Application of Research on Visual Factors in Stereoplotting," Photogrammetric Engineering, Vol. 30, No. 6, Nov. 1964, pp. 991-999.

1959 study of eye fatigue in stereoplotting in Denver office of USGS. Recommended higher level of ambient light: more comfortable and eliminated visual shocks of abrupt changes in light levels. Optometrist serving as consultant devised questionnaire to evaluate individual 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).

B.11 INTERPRETATION OF COMPLEX IMAGES

51. R. H. Kause, "Interpretation of Complex Images: Literature Survey," Goodyear Aerospace Report GER 10830, Rev. A, 10 February 1965, AD 614 703.

Selected references and abbreviated abstracts from this report of particular interest to photointerpretation are cited below along with additional references within this general category.

52. F. Rhodes, "Predicting the Difficulty of Locating Targets from Judgements of Image Characteristics," Aerospace Medical Research Lab Technical Document Report No. AMRL-TDR-64-19, March 1964.

Search time to locate targets.

Overall target difficulty.

Factors involved: target size, picture sharpness and contrast, picture detail, logical restrictions on possible target location, target shape and pattern, target location, target isolation, rater bias.

Conclusions: "Raters were able to make highly reliable and seemingly reliable judgements about complex perceptual characteristics of aerial photographs. There was no difference in reliability or validity between ratings made by PI's and those made by untrained students."

53. M. A. Whitcomb, ed., Visual Problem of the Armed Forces, Washington, D.C., NAS-NRC, 1962.

Proceedings included:

1. Vision under reduced stimulus conditions.
2. Perceptual problems of space travel.
3. Pictorial display for reconnaissance interpretation.
4. Visual processes and problems of battlefield surveillance in ground warfare

54. H. R. Blackwell, J. G. Ohmar and R. W. Brainard, "Experimental Evaluation of Optical Enhancement of Literal Visual Display," ASD Tech. Report 61-568, October 1961.

"When the probability of detection (in a photo) was low or moderate at gamma = 1, increases in gamma were accompanied by increases in the probability of detection; when it was high at gamma = 1, detection probability either remained unchanged or decreased slightly with increased gamma.

"Of the spatial filtering masks studied, some always reduced the probability of target detection, whereas the most effective increased this probability at the lower values of detection probability.

"....unless the probability of recognition is known beforehand, optical enhancement should be done only at operator's discretion."

55. R. E. Reilly and W. H. Teichner, "Effects of Shape and Degree of Structure of the Visual Field on Target Detection and Location," JOSA, Vol. 52, 1962, pp. 214-218.

Square fields generally superior to round ones.

56. J. N. Enoch, "Effect of the Size of a Complex Visual Display upon Visual Search," JOSA, Vol. 48, 1958, p. 867.

Greatest attention paid to center of screen.

For displays smaller than 9° subtense, as displays decreased, durations of fixation increased, interfixation distances decreased, concentrations of attention in the central area increased, and efficiency decreased.

57. E. S. Zaman, S. Hecht, S. Schlair and C. D. Hendley, "Size, Shape and Contrast in Detection of Targets by Daytime Vision," JOSA, Vol. 37, 1957, pp. 531-545.

"For small targets ($<$ 100 sq. min.) square targets require less contrast than rectangular ones for recognition. All measurements can be unified on the supposition that the visually critical region of a target is a ribbon just inside its perimeter and 1 min. wide. Evidently, contrast is not judged over the area of a target, but across its boundary."

58. R. Sadacca, "New Techniques in Image-Interpretation Systems," Presented at the Seventh Annual Army Human Factors Engineering Conference, 1960.

Improved PI performance.

1. Degree of confidence a PI expresses in his identification.

Expanding the scale by which interpreters express confidence in their judgements to a 5-point scale seems to achieve a more even distribution of accuracy percentages.

2. Efficient viewing-time periods

The average accuracy of the interpreters falls off the longer they examine the imagery.

3. Performance feedback to interpreters

Knowledge of how well they are doing may be effective in reducing the number of errors made by P.I.'s especially if feedback is made in such a way that they can see exactly what kind of errors they are making.

4. Repeated exposures to the same imagery

The accuracy (for a tactical exercise) for objects that P.I.'s reported, both times they examined the imagery, was significantly higher than for objects reported only incl. (53% vs. 34%)

5. Teamwork Procedures

P.I.'s working in groups of 2 or 3 show a marked decrease in the numbers of false responses and a lesser decrease in the number of correct responses.

59. R. Sadacca, J. E. Ranes and A. I. Schwartz, "Human Factors Studies in Image Interpretation: Vertical and Oblique Photos," USAPRO Technical Research Note No. 120, Dec. 1961.

Tests on graduates of Image Interpretation Course, Ft. Holabird.

Results indicate that having both vertical and oblique photos of a target area does not necessarily make for improved interpreter performances.

60. R. Sadacca, A. Castelnovo and J. Ranes, "The Impact of Intelligence Information Furnished Interpreters," HFRB Technical Research Note No. 117, June 1961.

Army P.I.'s furnished additional intelligence information; a larger proportion was consistently above the median in correct identification of objects in the photographs; this group also reported more objects where actually none appeared.

61. J. Zeidner, R. Sadacca and A. I. Schwartz, "The Value of Stereoscopic Viewing," HFRB Technical Research Note No. 114, June 1961.

Number of objects reported tended to be higher under the nonstereo viewing condition. Findings indicate: (1) need for stereo capability should be demonstrated before new display equipment is developed for use of military P.I.'s; (2) future studies should examine additional interpreter functions and systematically take into account such photo factors as quality, content, and format.

62. C. A. Baker and W. F. Grether, "Visual Presentation of Information," WADC Tech. Report WADC TR-54-160, Aug. 1954.

General human engineering recommendations for aiding in design of the most satisfactory visual presentations of information.

1. Mechanical Indicators
2. Warming Devices
3. CRT's and Signal Coding
4. Printed Materials
5. Instrument Panel Layout
6. Lighting
7. Visual Detection and Identification

63. J. M. Enoch and J. A. Fry, "Visual Search of a Complex Display: A Summary Report," The Ohio State University Mapping and Charting Research Lab, MCRL T. P. No. 696-17-282, April 1958.

A series of eight experiments to identify major factors encountered in search performance.

64. G. A. Fry and C. A. Townsend, "The Effects of Controlling the Search Pattern of a P.I.," RADC Tech. Report RADC TN-59-533, Sept. 1959.

Machine-generated search patterns (using a ring or outline square) that give complete and uniform coverage are useful primarily when the targets are difficult to find. Under good visibility free search is much preferred. Under these conditions, peripheral vision is more effective, and tests show that on the average, free search represents a faster way of finding a target.

65. G. A. Fry and J. M. Enoch, "Human Aspects of Photographic Interpretation Fourth Technical Report," The Ohio State Mapping and Charting Research Laboratory, MCRL 4th I.T.R., AD 232 142.

Markedly increased probability of detection in the center of a photo.

66. G. A. Fry, "Human Aspects of Photo Interpretation (Addendums to Final Summary Report)";RADC Tech. Report 61-29B, May 1961 (Secret).

Studies effect of photo grain, blur, contrast, size and shape on photo interpretation; image-enhancement techniques, TV grain; search patterns, possible control and usefulness in assessment of P.I.'s task.

67. M. N. Crook, "Visual Factors Affecting Efficiency in the Task of Photo-interpretation," Feb. 1960, ASTIA Document 232 175.

1. General illumination.
2. Illuminance for color transparencies.
3. Differential illumination in stereo viewing.
4. Binocular viewing of duplicate photos.
5. Visual fatigue.

68. S. L. Smith, "Color Coding and Visual Search," Journal of Experimental Psychology, Vol. 64, 1962, pp. 434-440.

Series of colored targets against either white or black background. When target color was known in advance, search times were considerably shorter than when unknown. Where target color was unknown search times were not significantly different than those for single-colored display.

69. D. E. MacDonald, "Criteria for Detection and Recognition of Photographic Detail," BU ORL Tech. Note No. 72, Oct. 1950.

Worthwhile discussion of role of P.I. and need to raise his ability to raise the overall quality of aerial reconnaissance.

70. Philco Advanced Technology Laboratory, "Semiautomatic Imagery Screening Research Study and Experimental Investigation, Vol. I," July 1963, ASTIA Document AD 410 261.

Discusses photoscreening problem and possible design solutions.

71. R. J. Hall, J. W. Miller, D. Musselman, R. Earl, and M. H. Detambel, "A Study of Visual Display Enhancement and Techniques of Color Filtering," Electronic Systems Div. Tech. Document Report 63-635, Dec. 1963.

Viewing filtered photos proved superior to viewing the unfiltered ones. Differences resulting from the two degrees of display control were small but favored the condition of more complete observer control. Operators had choice of one-at-a-time viewing or superimposing. Those with this freedom found increased detectability.

72. C. L. Klingberg, C. L. Elworth and C. L. Kraft, "Identification of Oblique Forms," Tech. Report No. RADC-TDR-64-144, Aug. 1964, AD 607 357.

Oblique photography (aerial recon.). Discusses form constancy - refers to identity in perception of plane forms as they vary in orientation or projection transformation. Complete form constant, doesn't exist, so they are preferred viewing angles for best discrimination or recognition performance. This "best view" may be desired either because the salient features of an object are more apparent or because the mental picture of the objects corresponds to the view.

Reduce search time by:

1. Being selective in the type of photography obtained.

2. Being selective by presenting the most promising imagery to the P.I. first, instead of having him waste time in less useful material.

What a P.I. sees in a photo depends on his past experience, near and remote. Probability of seeing (i.e. being cognizant of) a given target depends in part on his expectancies. Higher probability of detection if told to expect a target. Detecting probability affected by wishes - leads sometimes to false reports.

If experience has been with one view, detection probability may be much lower than for a P.I. having fewer but more varied views of the target.

Quote by Hake:

"Thus perception itself, or the ability to 'see' a form demands prior information about what forms generally are like in the world. And conversely, memory for a particular form is stored not as an isolated description but in terms of the categories of experience found useful in the past in interpreting input information about forms. It is convenient to talk of these categories as 'schemata' - maybe a preferred schemata (i.e. orientation of, e.g., drawing a truck.)"

Boynton and Bush (1955) indicated that they were unable to obtain evidence of detections without recognition, that is, a critical target response when one was actually present in the array, but a response which was incorrect as to which of the six classes of critical target it belonged.

Boynton & Bush:

Detection - observer identified an object of interest but can't categorize it further.

Recognition - observer identifies object as belonging to a particular class of objects or as having particular attributes. This can be broken down into increasingly specific categories. Recognition implies prior experience since one cannot categorize a completely novel object.

Conclusions - Near vertical best for aircraft, high oblique best for ships.

73. Harriet W. Foster, "Information Displays and Information Processing Tasks," SDC SP-1811, Sept. 9, 1964.

Ordinarily one thinks of a visual search task as a search for a known target. It should be clear, however, that the uncertainty concerning what kind of target will appear can vary from complete certainty to extreme uncertainty, such as a search for "something interesting," for example.

74. Robert W. Brainard and George N. Ornstein, "Image Quality Enhancement," North American Aviation, Inc., AMRL-TR-65-28, Behavioral Sciences Lab, Wright-Patterson AFB, AD 616 895.

Enhancement of photos using flying spot scanner to obtain a video signal and then adding its first and/or second derivative(s). Resolution, contrast and acuitance measured. Results indicated differentiation enhances image quality, greatest enhancement occurring with operations involving second-order differentiation.

Edge-gradients play significant role in visual perception. Perceived contrast is "formed over the boundary of an object" (Perrin, F. H. - "Methods of Appraising Photographic Systems, Part I, - Historical Review": J. SMPTE, 69: 151-,56, 1960) that is, over the spatial-luminance transition connecting adjacent areas.

If the edge-gradient is sufficiently shallow, the difference between adjacent luminance areas in an image will not be detectable even though the brightness differential, i.e. contrast between the two areas is well above contrast. Also by properly shaping the edge-gradient, the apparent contrast may be made to oppose that of this actual spatial-luminance distribution of the image, and in some cases to produce apparent contrast where none actually exists.

With blurred images, having significantly reduced edge-gradients search time increases the duration of the visual fixations increases and the distance between fixations decreases as the edge-gradients are diffused. Rationale for enhancement technique.

Even with sharp edge-gradient between object luminance areas the distribution of illuminance at the retina will be spread or diffused due to diffraction, spherical and chromatic errors, scattering of light. In spite of this, the retinal image is often perceived as being sharp and distinct. Perception of bipartite field - edge-gradient much sharper than retinal image would indicate;- observed first by Mach, who suggested that the effect was describable as a second derivative correction applied to the retinal image. The equation proposed was

$$r(x) = \alpha \log \frac{e(x)}{\beta} \pm \frac{\gamma}{e(x)} \frac{d^2 e(x)}{dx^2}$$

where x is the axis along the retina surface

r is the perceived (or apparent) brightness

e is the retinal illuminance

α, β, and γ are constants.

Mach also found first derivative of spatial-luminance distribution has little or no effect on perception.

B.12 MISCELLANEOUS AND GENERAL

75. One of the most useful source references on the subject of vision is the Annual Review of Psychology, published by Annual Reviews, Inc. of Palo Alto, California. Each year a different author searches the literature and presents an up-to-date review of activities in the field of vision. Of particular value is the very extensive bibliography which is published at tne end of each review.

The bibliography of the Annual Reviews of Psychology is listed below.

Bartlett, N. R.: Vision, Vol. 1, 1950
Chapanis, A.: Vision, Vol. 2, 1951
Helson, H.: Vision, Vol. 3, 1952
Vernon, M. D.: Vision, Vol. 4, 1953
Riesen, A. H.: Vision, Vol. 5, 1954
Thomas, G. J.: Vision, Vol. 6, 1955
Mueller, C. G. & Berger, E.: Vision, Vol. 7, 1956
Pickford, R. W.: Vision, Vol. 8, 1957
Riggs, L. A.: Vision, Vol. 9, 1958
Gebhard, J. W.: Vision, Vol. 10, 1959
Hurvich, L. M. & Jameson, D.: Color Vision, Vol. 11, 1960
Mueller, C. G.: Visual Sensitivity, Vol. 12, 1961
Boynton, R. M.: Spatial Vision, Vol. 13, 1962
Armington, J. C. & Biersdorf, W. R.: Color Vision, Vol. 14, 1962
Onley, J.: Visual Sensitivity, Vol. 15, 1963
Westheimer, G.: Visual Acuity, Vol. 16, 1964
De Valois, R. L. & Abramov, I.: Color Vision, Vol. 17, 1965

76. ______"Human Factors Design Standards for the Fleet Ballistic Missile Weapon System," Vol. I - Design of Systems, Vol. II - Design of Equipment, May 1963, NAV WEPS OD 184 134

77. Davson, op. cit.

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 psychological factors.

78. G. Kepes, ed., Education of Vision, Vol. I, Vision and Value, George Braziller, 1965.

In Volume I of this three volume 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 for other means of knowing. Holton, a physicist, discusses vision as implement for understanding physical world.

79. A. C. Crombie, "Helmholtz," Scientific American, Vol. 198, No. 3, March 1958, pp. 94-102.

Helmholtz was trained in medicine and was physicist, physiologist, and philosopher. Gave law of conservation of energy its broadest and most definitive formulation. Study of optics; invented ophthalmoscope; physics of sound and theory of 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 between sensation and 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 electrical and magnetic forces: Three rival theories of electromagnetic forces existed. Helmholtz showed that all three were special cases of a more general mathematical theory and devised tests to determine which special theory to be adopted. Left with that of Faraday and Maxwell that electric and magnetic forces are propagated through an all-pervading ether. Mathematical interpretation of Maxwell's theory that light is another form of electromagnetic wave stimulated Hertz to make experiments in electromagnetic radiation, which established theory of light and made radio communication possible.

80. Rene Dubos, "Humanistic Biology," American Scholar, Vol. 34, No. 2, Spring 1965, pp. 179-198.

Success of comparative biology may have retarded growth of knowledge about man himself. All living forms have many characteristics in common; biologists and medical scientists tend to focus investigation on organisms simpler and easier to manipulate in lab (e.g., horseshoe crab). This tendency is based on widespread (but unproved) assumption that understanding of man will eventually emerge from detailed knowledge of elementary structures and 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 and 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 between man and environment. At one extreme man appears as ordinary (though complex) physiochemical machine, reacting with environmental 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 he responds actively and creatively. Can 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.

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

These biological traits have been grossly neglected by biologists. This neglect is the result of the historical accident that scientific biology has been identified from its beginning with concept that body is complex but otherwise ordinary machine and that detailed analysis of its elementary structures and energy mechanisms is the only valid approach to the understanding of the living organism. This attitude has discouraged the scientific study of biological 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 and pronounced characteristics. Failure of theoretical biology 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 and senses are conditioned by repeated experiences. Environmental influences also determine certain patterns of response which can affect all manifestations of behavior, for example, endless variety of conditioned responses from dog salivation to Proustian association with past.

Activity of neural processes in brain is continuous. Stimuli give form to the activity 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.

Systematic effort should be made to describe and analyze pattern of responses that man makes to all the stimuli that impinge on him. Such knowledge could be acquired if biologists devoted to study of living experience as much skill and energy as have devoted to description of body machine.

Animal kingdom provides experimental models for many of interesting problems of human life. Biologists have been immensely successful in describing elementary structures and processes of body, but have neglected study of living experience. Commonly stated that biology has become "too scientific" to concern self with problems of humanness. In author's opinion difficulty is that biology is not scientific enough. One of responsibilities of science is development of objective methods for describing all aspects of reality.

81. Bernard Berelson and Gary A. Steiner, Human Behavior: On Inventory of Scientific Findings, Harcourt, Brace, & World, 1964. (Reviewed by Jules Henry in Scientific American, July 1964).

Publication 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 distinguish 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 important minor percentages; (7) issue-avoidance; (8) drawing of simple-minded parallels; (9) multiparaphrasis or repeated quotation and 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 experiments 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, he 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 sees a richness that somehow has fallen through the 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 and 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."

82. Davson, op. cit.

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, especially when these effects are slight (Stiles, 1954).

Formula for calculating equivalent 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 probably negligible for a few degrees of angular separation between field and fixation point (Pirenne & Denton 1951).

 ROBIN

INTRODUCTION

This paper describes a program of investigation into the areas of vision, fatigue and illumination as these matters relate to the P.I. task. The paper suggests area investigations through literature search, through evaluation of current work and through interviews with the active research workers to obtain comprehensive data in each field. Once collected, that data will be "filtered" through the medium of technically competent, experienced P.I.'s and will then be synopsized in handbook form with a supporting bibliography. Further, a continuing lower level of effort is proposed beyond completion of the initial study to maintain currency of information within the three indicated fields.

THE PROBLEM

The effective accomplishment of a research, development and planning responsibility requires a high degree of currency in many technical and scientific disciplines. Normally, only limited amount of the investigative work accomplished in any one discipline is germain to the P.I. task. Thus, if the useful data are to be made available to the development or planning officer, that person must research through voluminous amounts of material to find the limited pertinent information.

The information is vital to successfully accomplish the R & D task.

The time requirements for obtaining the required information falls beyond the capability of the R & D group who are normally faced with significant numbers of other priority tasks.

SUGGESTED SOLUTION

STAT

[redacted] proposes herewith, to undertake, in close liaison with the customer's technical representative, a program designed to make readily available all pertinent research results that stem from sound research in the fields of:

1. Vision
2. Fatigue
3. Illumination

The program will concern itself solely with those aspects of the investigative results which will be contributory to a group concerned with the optimization of an image analysis system. This separation of the useful data from the non-contributory shall be achieved by having all materials obtained reviewed for pertinency by one or more persons experienced in national level P.I.

Phase one of the program shall consist of an extensive search of published works to thus gain useful data.

Periodical publications to be reviewed include, but are not limited to:

a. American Scientist
b. Applied Optics
c. Vision Research
d. Journal of the Optical Society of America
e. Optica Acta
f. Science
g. Scientific American
h. American Journal of Psychology
i. Canadian Journal of Psychology
j. Journal of Applied Psychology
k. Journal of Engineering Psychology
l. Journal of Psychology
m. Perceptual and Motor Skills
n. Soviet Psychology
o. Illuminating Engineering
p. Industrial Lighting News
q. Journal of SMPTE
r. Lighting
s. Optics and Spectroscopy
t. British Journal of Psychology
u. Science Progress
v. Science of Man

Books and similar works to be reviewed include, but are by no means limited to:

a. Stevens, S. S. - HANDBOOK OF EXPERIMENTAL PSYCHOLOGY Wiley & Sons, 1963.
b. Shurcliff, W. A., - POLARIZED LIGHT - Harvard Univ., 1962.
c. Pollock et all - OPTICAL PROCESSING OF INFORMATION, Spartan Books, 1962.
d. Wolf, E. - PROGRESS IN OPTICS, Volumns I, II, III, Wiley & Sons, 1961-1962-1964.
e. Granit, R. - RECEPTORS AND SENSORY PERCEPTION - Yale Univ. Press, 1955/62.
f. Luckiesh & Moss - THE SCIENCE OF SEEING - Van Nostrand, 1938.
g. Brindley, G. S., PHYSIOLOGY OF THE RETINA AND THE VISUAL PATHWAY - Edward Arnold (London) 1960.
h. Henkes, H. E. et al, FLICKER, Junk (The Hague) 1963.

Also the extensive holdings of the Defense Documentation Center will be reviewed for pertinent research and reporting.

The second project phase shall consist of personal or mail contacts with those authors and industries found in Phase I, whose past publication work will probably be of value in the preparation of a P.I. R & D group's"Tabulation of Pertinent Research Results".

In addition to persons "found" in the publications search, additional research workers can be interviewed on the suggestion of the earlier contacts or at the behest of the sponsoring organization. Each such personal contact would be cleared with the sponsor's representative before implementation.

The third phase of the proposed work shall consist of a tabulation of significant results into a handbook format for use by the sponsor. In addition, a full bibliography of useful research is proposed (and will be referenced as required in the handbook) to permit the user to quickly establish the identity of an individual research worker and the full range of his experimentation, if his results are referenced or included within the "Handbook".

Additional work on a continuing basis is recommended in order that the handbook and its companion bibliography shall remain current and in order that equipment/system design and planning shall take full advantage of knowledge gains in vision, illumination and fatigue as they relate to P.I.

REPORTING

Spot reports shall be submitted in all cases where work of high pertinency is uncovered and should such work recommend, by implication or analysis, specific action by the R & D group, that action shall be suggested within the report.

Should specific voids in research become apparent in the latter phases of the project, the sponsor's attention shall be called to those lacks in order that they may be examined as subjects for sponsored research.

The proposed Handbook and Bibliography shall serve as a Final Project Report except that an additional project "History" shall be submitted as a basis for evaluation of the depth and thoroughness of the proposed investigation.

PERSONNEL

STAT

It is recommended that [redacted] function as Project Manager for the proposed effort. This recommendation reflects [redacted] maturity and judgment. He has been an active P.I. since 1952 and was employed as a P.I. within CIA from 1956 to 1962. STAT

It is further recommended that [redacted] function as the principal research worker in the areas of document search and data compilation. [redacted] experience in preparing [redacted] the "Manual of Photographic Interpretation" provides an eminent qualification for her inclusion in the proposed effort. Personnel resumes of both persons are included with this proposal. STAT

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In addition to [redacted] STAT
STAT [redacted] would be available for consultation
STAT as needed. [redacted] last assignment before joining [redacted] STAT
was Chief/Publications Division CIA/PIC. [redacted] was a Photo STAT
Intelligence Officer with CIA from 1953 to 1961 and functioned as a
member of the development staff of that organization for two years.
STAT [redacted] expertise covers both the vision process and color technology. Resumes of these persons are also attached hereto.

Next 8 Page(s) In Document Exempt

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