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A STUDY OF INDIVIDUAL VARIABILITY IN DARK ADAPTATION AND NIGHT VISION IN MAN

DECEMBER, 1970

Prepared for

LIFE SCIENCES DIVISION, ARMY RESEARCH OFFICE
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
DEPARTMENT OF THE ARMY
WASHINGTON, D.C. 20310

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The findings in this report are not to be construed as an official Department of the Army position

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FEDERATION OF AMERICAN SOCIETIES
FOR EXPERIMENTAL BIOLOGY
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FOREWORD

This is a technical report prepared for the Life Sciences Division, Army Research Office, Office of the Chief of Research and Development, Department of the Army, by the staff of the Life Sciences Research Office, Federation of American Societies for Experimental Biology, in accordance with the provisions of U.S. Army Contract No. DAHC19-70-C-0022. This study is one of a series in the biomedical sciences undertaken by the staff to provide scientific assessment of a subject based upon a comprehensive critical literature review and the views of knowledgeable scientists actively engaged in research in the field. The report develops a factual basis for subsequent discussions by research administrators.

We acknowledge the contributions of the numerous investigators who have assisted with this study. A judicious attempt has been made to incorporate the different points of view; however, the authors accept the responsibility for the contents of the report.

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SUMMARY

This report provides a comprehensive analysis of the significance of individual variation in human night vision capability. It reviews the origin and magnitude of inter- and intra-individual variation in the several physiological and behavioral processes that constitute dark adaptation and scotopic vision. The genetic, somatic, and behavioral factors that exhibit variation and the environmental factors affecting variation are discussed. The report identifies gaps in this knowledge that bear on the requirements for efficient night vision in the soldier. The report suggests that recognition of individual variation is critical to the concept of selecting key individuals for specific duties requiring night vision capability.

TABLE OF CONTENTS

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I. STATEMENT OF THE PROBLEM

This study was undertaken to provide the Life Sciences Division, Army Research Office, Office of the Chief of Research and Development, Department of the Army, with a comprehensive review of the significance of individual variation in dark adaptation and night vision. This report supplements the brief review of individual variability presented in the 1969 report, A Study of Vision as Related to Dark Adaptation and Night Vision in the Soldier (Fisher *et al.*, 1969).

Biologically and historically man has developed a cyclic pattern of increased activity during daylight and reduced activity at night. In part, this behavioral pattern results from a dependence on vision for reception of environmental stimuli. Modern man extends his daylight activities by artificial illumination to enhance photopic vision, and military operations are no exception.

Nocturnal military activities basically depend on the night vision capability of the individual soldier and on equipment that enhances this ability. In recent years, devices have been developed that improve vision at low light levels. The use of these devices under reduced illumination has made possible the concept of continuous military operations. However, efficient use of night vision devices depends upon the recognition of the limitations of the visual capabilities of the individual soldier.

Human capacity to see at night is notoriously inconsistent. It depends on the individual's level of dark adaptation, but also includes other physiological and behavioral components. Dark adaptation and night vision involve increased visual sensitivity resulting from exposure to a decreasing quantity of visible light. Yet among individuals exposed to identical conditions, the rate and final level of dark adaptation and the ability to see at night show wide variation. Similarly, dark adaptation and scotopic ability vary within the individual with time. Thus the concept of continuous and sustained operations suggests a reevaluation of the importance of individual variation in night vision.

Because night vision is markedly affected by motivation, experience, training, and other behavioral factors, vision under

reduced illumination is not synonymous with actual scotopic sensitivity. Historically, the ability to see at night has been evaluated in terms of parameters that can be assessed objectively or subjectively. Three general approaches have evolved: a) measurement of physiologic parameters physiologically, e.g., determination of visual pigment concentrations; b) evaluation of physiologic changes behaviorally, e.g., measuring dark adaptation rates or scotopic thresholds; and c) behavioral effectiveness in task accomplishment, e.g., performance of tasks at low luminance levels. An inherent aspect of the problem of assessing night vision capability is generalization from the first two approaches to the third.

The significance of individual variability in seeing at night as it influences performance of military tasks is incompletely understood. It is desirable to know the origin and magnitude of these differences and how they may influence a man's performance. Furthermore, it seems logical to determine the overall night vision capability of the individual when he is assigned to a particular civilian or military task. This information, if sufficiently dependable, may permit the selection of key individuals for specific tasks and exclusion of others who should not be assigned responsibilities that require critical night vision.

For these reasons, this study has focused upon: a) the current state of knowledge of individual variability in dark adaptation and night vision in man, and b) identification of the gaps in this knowledge as they bear upon military needs for scotopic capability.

II. SCOPE OF THE STUDY

Historically, individual differences in night vision have been of military and scientific interest. This subject received considerable attention during World War II and the following decade. Since that time, however, relatively few reports have appeared with extensive population data on healthy or diseased young males. It is recognized that night vision ability varies among individuals. In addition, the speed and degree of dark adaptation varies from person to person and, possibly, in the same individual from time to time. This study includes a review of literature reports of such factors as age, state of health, and nutritional status that are related to individual variability in dark adaptation and night vision. Unfortunately, there is no recent comprehensive review of this subject. Indeed, a recent Conference on The Biology of Human Variation did not include papers on variability in human vision (Weyev *et al.*, 1966). Nevertheless, evidence from many investigations suggests that individual variability may be substantial.

This study reviews a number of variables that may influence dark adaptation and night vision. These include, but are not limited to: genetic background; hereditary diseases; environmental factors, especially noxious stimuli; overt pathology; and biochemical, metabolic, and nutritional status of the man.

The study considers both variability among individuals and variation within the individual over time. Differences from man to man in otherwise similar populations exposed to similar experimental or natural conditions as well as genetic, somatic, and behavioral factors are considered. Changes in the individual man from time to time include the effects of smoking, drugs, environmental modification, and nutritional deprivation such as fasting. It is recognized that the evaluation of individual variability in dark adaptation and night vision involves investigations on both large numbers of men and intensive study of a few individuals.

This study provides background information potentially useful in planning of future biomedical and behavioral research related to the development and efficient utilization of night vision devices, further evolution of night vision training, and military operations

that require consideration of variability and limitations of the night vision capability of the man.

III. THE CONCEPT AND EXPRESSION OF INDIVIDUAL VARIABILITY

The presumed fundamental requirement for a "normal" or "average" value of a measurable phenomenon poses a unique problem in biology and medicine. The statistical treatment of biological data, influenced by such factors as experimental techniques, inherent variation in individual values, and problems in sampling techniques is one way to express biological variation.

The classical orientation of biomedical research has been to derive from observational data generalizations that describe universal principles inherent in biological phenomena. Experiments and observations are made on individual organisms, and from these the investigator attempts to deduce those common features that apply to all individuals, or extract that aspect which is common to all circumstances. Routinely, the investigator attempts to avoid consideration of individuals *per se* by studying large numbers of individuals and treating the observational data statistically. In this context, it is not surprising that most biomedical researchers view individual variation as an impediment to recognition of general principles. The elimination of individual variability is attempted, or minimized, by repetitive experimentation or use of large numbers of individuals. If results are highly variable and no general mechanisms can be discerned, the experimenter searches for procedural or measurement errors, loses interest, and frequently overlooks biological variability (McCammon, 1966; Simonson, 1966).

On the other hand, investigations on populations are seldom concerned with differences among individuals. Even when variability between individuals is recognized in population studies, the problem of intra-individual variability remains obscure (McCammon, 1966). This second source of individual variability – within the person from time to time – does not cause difficulties in estimation of group or population means and ranges. However, it does become a problem with respect to assessing the relationship between the various inherent parameters of the process under study. The general aspects of human variation are often considered in the discussion of human genetics. As recently as 1966,

the subject of human variation was reviewed in great detail (Weyev *et al.*, 1966).

Williams (1956, 1967) has championed the study of the individual in lieu of the study of abstract population mean, or the "average man" concept. It is interesting to note that in the 1966 symposium (Weyev *et al.*, 1966) and in other recent reviews (Williams, 1956, 1967), there is very little mention of, or data on, one of the most variable human physiological processes, dark adaptation and night vision. This is ironic, in that visual science is one field where individual differences are acknowledged. The ophthalmological examination is oriented to examination of the specific visual problem of the patient. Refractive correction is based upon the individual; not only lens power and characteristics, but also bridge size, lens size, temple length, and other individual factors are considered.

Dark adaptation and night vision are not one process, but a complex series of processes that result in an altered sensitivity to light. Thus, over the years, numerous investigators have recorded data on a sufficient number of subjects to arrive at "normal" values, but usually they have measured one aspect of the phenomenon with different experimental techniques. Dark adaptation involves several changes that result in increased sensitivity of the visual system following a reduction in ambient illumination. The adaptive process includes several independent physiologic processes, including an increase in pupil diameter and increased sensitivity of the photoreceptive cells in the retina, a conversion from the dominance of cone vision to rod vision, and a shift in neuropathways within the retina. Thus, any stated "normal range" or "average value" for this sensory capacity is indeed a statement of the changing ability of a complex system. Furthermore, quantitative measurements must include reference to the circumstances under which the observations were made and the specific process measured.

A. STATISTICAL ASPECTS OF BIOLOGICAL VARIATION

The concept of variation is of concern in biometrics; statistical methods are useful in the study of biological variation. Generally, it is assumed that variation means variability in data around a specific value. Biologic variation is inherent in any complex physiologic process that is affected by numerous variables which are difficult to control. For example, several parameters of dark adaptation and night vision provide either ordinal or real data that are amenable to statistical evaluation. As might be expected, even when the methodology of measurement is rigidly standardized, the values vary from one individual to another.

Normal values for rate of dark adaptation, absolute or contrast threshold, and other quantifiable aspects of dark adaptation are usually expressed in terms of the mean and the range of values. These data can be handled by several well accepted techniques of biometric analysis and statistical inference. Individual values plotted by frequency of occurrence produce a frequency or normal distribution curve. In the early literature, normal distribution curves and actual data are often reported. More recent studies of phenomena in the visual process measure a single or multiple variables sufficiently to satisfy statistical inference procedures. Most studies are directed toward understanding of the phenomenon rather than the individual variations. Thus statistical procedures are useful in establishing the probability of the mean observation value as the population norm rather than the existence of a normal range *per se*.

Vandenberg (1966) has recently reviewed the techniques of statistical analysis of human variation. Techniques of single and multivariate analysis, nonlinear factor analysis, and computer utilization that have been developed in genetic and behavioral studies could be useful in reevaluating the relationships among the parameters of dark adaptation and night vision. While many observations have been made over the past fifty years, raw data from many of these studies have been lost. Vandenberg (1966) points out that in all areas of scientific endeavor, organized efforts at storage and use of archival data would be most useful. This need has become evident in the conduct of this review of longitudinal studies.

B. THE GENETIC BASIS OF INDIVIDUALITY

The characteristics of an organism are fundamentally the expression of hereditary capability, as modified by environmental influences. Without belaboring the importance of the genetic mechanism, it is logical to make the basic assumption that what is inherited by an organism is a sufficient amount of genetic information which provides a range of capacity to respond to a range of environmental stimuli. While the genetics of dark adaptation are not fully understood, variations in and among individuals appear to be continuous rather than discontinuous, with the exception of congenital abnormalities (see p 51).

The role of genetic effects in the expression of individual variability can be observed from the investigations of Post (1962b) who studied the effects of "selection pressure relaxation" on anomalous color vision and aberrations in visual acuity. In a review of previous data (Post, 1962a) suggested that there is a somewhat higher incidence of anomalous color vision and aberrations in visual acuity in civilized societies than in primitive societies. He concluded that the relaxation of selection pressure for critical vision is a factor in the disuse of this visual ability in modern civilizations. Thus survival of modern man does not depend as critically on his visual ability. It would be of interest to determine the extent of inherited dark adaptation ability in primitive and civilized populations in the present decade. It would be extremely difficult to separate the hereditary basis of night vision from the learned or behavioral components; however, there does not appear to have been any population study of night vision threshold values to determine if this is a genetically-determined trait. A genetic study should be made on the human variability in dark adaptation threshold to correlate differences between individuals where genetic relationships are known.

C. ENVIRONMENTAL ALTERATIONS

The genetic constitution of an individual provides the capacity to respond to a diversity of environmental influences. The pressure of environmental factors on a complex biological system produces effects that reflect the inherent capacity of that system to respond. These effects may form a continuum of slightly different responses over a wide range or may be expressed as discrete traits. The latter are more easily studied experimentally, but even here new investigative techniques are sorely needed (McKusick, 1964). One such approach has been developed by Dubos (1969) who has recently reported on the subtile effects of early influences of environment on subsequent development of neural systems and behavior patterns in animals.

Even in the most carefully controlled investigations, environmental variables induce fluctuation both among individuals and within individuals over time. Preexposure to light, transitory dietary or work-rest changes, and other factors produce changes in dark adaptation and night vision and modify what would be considered normal values. Similarly, altitude, season, and ambient temperature extremes may function as stressors and affect night vision capability.

In this study, only those environmental variables that have been shown to influence night vision have been reviewed in detail. These are primarily hypoxia, toxic particulates, and gases that induce adverse effects on vision.

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IV. INDIVIDUAL VARIATION IN SCOTOPIC VISION

A. HISTORICAL INTRODUCTION

Night vision capability was recognized as a subject of paramount importance in the early days of World War II. Demands for increased numbers of convoy lookouts, drivers, pilots, and aircraft spotters produced an urgent need to understand the various aspects of dark adaptation and night vision. The efforts of the scientific community to respond to these military demands were coordinated by the National Academy of Sciences-National Research Council and the National Defense Research Committee. These groups evolved into the Armed Forces-NRC Committee on Vision and provided a central facility for cooperative efforts and exchange of information among scientists in the Allied countries.*

The investigations were conducted by numerous scientific and technical institutions, and by military research groups that were established with the help of the Armed Forces-NRC Committee on Vision. The reports were disseminated to participating laboratories to maximize research coordination and planning. However, the scientific results were a critical military resource; and thus, the majority of these reports were classified.

Many of these classified studies were issued as reports rather than published in the open literature. A majority of these reports have been maintained in the files of the United States Armed Forces-National Research Council Committee on Vision Minutes and Appendices. Following the cessation of hostilities, the reports were unclassified and made available to qualified scientists interested in dark adaptation and night vision. In 1949, Berry published a review and annotated bibliography of these wartime studies of dark adaptation, night vision testing, and related topics.

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* We are indebted to Dr. Milton A. Whitcomb, Executive Secretary, NAS-NRC Committee on Vision, for the opportunity to read the minutes and reports of the Committee on Vision, 1944 to 1970.

This document is a definitive and thoughtful analysis of the research efforts in this field and includes comments upon the origin and orientation of research efforts within the United States during the period 1939 - 1949.

The initial efforts of investigators in these wartime studies were directed toward establishing the incidence of night blindness by surveys of military populations, comparing these observations with previous laboratory studies, and educating personnel on night vision testing and training (Miles, 1949). The summary of these investigations indicated that (as of August, 1941):

(1) night vision is not a pressing problem, since few of the military personnel examined exhibited clinical night blindness;

(2) the state of the art at that time was not sufficiently precise to allow elimination of personnel in selection procedures on the basis of a single measurement of thresholds for flash or form recognition;

(3) selection of personnel for night duties could not be made on the basis of a single test;

(4) there was a need for improvement in intensity and color of cockpit illumination;

(5) preadaptation to reduced ambient light was desirable prior to nighttime military missions;

(6) there was an urgent need for a night vision test to screen large numbers of men.

These six conclusions provided a basis of orientation and direction to subsequent research on night vision problems.

These conclusions led to the widespread testing of large numbers of soldiers. Thousands of men in the Armed Services were tested in various selection programs. During the early 1940's, numerous laboratory examinations were developed for testing night vision. These types of night vision screening included numerous simple and elaborate schemes that measured one or more aspects

of night vision capacity. The results suggested that the simple night vision screening tests were as valid as the more elaborate and complicated tests in establishing the prevalence of night blindness.

In a retrospective review of these wartime studies, Verplanck (1949) noted that all investigations of visual performance below a specified light level were considered as studies on "night vision." Verplanck stated:

> "And our job was to find out 'how much,' or 'how good' 'night vision' various individuals had. By and large, our efforts were limited to a search for the best 'test' of this 'capacity.' Some of us, at intervals, or should one say, at lucid intervals, would question this assumption of a unitary capacity, and point out the obvious fallacies involved. But such intervals were brief, the search for a test was resumed, and the experimental analysis of visual behavior which should have been made, never appeared. Back we went to the development of 'a test of night vision,' which would have been accepted as satisfactory, if only it gave statistically reliable results. If a reliable test was obtained, validation tests were planned, but there were questions as to the necessity of such a step."

The development and use of several night vision tests during this period led to the conclusion that measurement of night vision was necessary since there are individual differences sufficiently large to warrant testing of an individual's capacity (Anonymous, 1949). In his review five years later, Verplanck (1949) concluded that the work on night vision testing was useful in selecting personnel for night duties and eliminating the small number of individuals that were congenitally or nutritionally night blind. He recognized that dark adaptation and night vision was not a unitary capacity but involved a variety of visual and nonvisual physiological and psychological factors. More specifically, Verplanck concluded that visual performance, both within the individual and among individuals, is extremely variable. It would not be impossible to develop a basis for selection of men with superior scotopic capability, but the task of evaluating criteria for screening night vision ability required a fresh approach. Verplanck (1949) concluded with

an outline of the sequential research programs that would be required in building a battery of visual performance tasks.

In a recent review of much of the same literature, but including the contributions of the British Admiralty Laboratory and the Canadian researchers, Harvey (1970) reached a similar conclusion as to the validity of the night-vision testing studies conducted during World War II. He pointed out that in spite of the fact that large numbers of individuals were tested for night vision and dark adaptation, it is regrettable that so few data showing means and standard deviations in absolute units which would be amenable to comparison are available in these reports.

In deference to these early workers, it should be noted that the purpose of testing was to classify soldiers primarily with respect to the occurrence of clinical night blindness and secondarily in terms of their night vision ability in selection and screening processes. But, as Harvey (1970) noted, it is unfortunate that more of these data were not expressed in scientifically more meaningful forms. The mass of the material on different testing procedures did not reveal more substantive information about night vision testing and the test variation that occurred. Harvey (1970) concluded that of the adaptometers utilized during the Second World War period, only the Admiralty Research Laboratory (ARL) adaptometer, the Hecht-Shlaer, and possibly the National Defense Research Council (N. D. R. C.) adaptometers were designed sufficiently well for critical laboratory use. Even these devices do not have high test-retest reliability and, in addition, the coefficients of variation between tests of the same individuals with different adaptometers were extremely high (Harvey, 1970). This lack of reliability may indicate use by unskilled personnel, faulty experimental techniques, or lack of sufficient reliability in the machines or in the techniques themselves. Unfortunately, the extent to which individual variability affected these results cannot be determined from the extant data.

Despite the enormous volume of research in the interim, Kinney, in 1962, concluded that there was good reason to believe individual differences were sizeable, meaningful, and could be valid predictors of performance at night. Two newer test methods had been developed in the intervening years that were useful in establishing intra- and inter-individual differences in scotopic capability (see p 24). The Naval Medical Research Laboratory

(NMRL) test procedure measures scotopic sensitivity over a known area of the retina, using objects of different size or brightness in several locations of the visual field. The test has been used to establish seasonal and individual differences in scotopic sensitivity (Sweeney *et al.*, 1960). The second, the Army Night Seeing Tester (ANST) was developed to measure brightness contrast sensitivity and visual acuity detail (Uhlaner and Zeidner, 1961). Although compact and portable for field use, the ANST has not been widely used, although it was successfully field-tested in conjunction with training for enhancement of night vision capability (Sharp *et al.*, 1952).

In a later review of literature and her own studies on individual differences, Kinney (1968) discussed the reliability of test procedures for determination of variations in mesopic and scotopic vision with respect to performance of military tasks.

Since 1943, the study of individual variability has been approached repeatedly by numerous investigators in a number of ways. In retrospect, it would seem that the early studies of Hecht and Mandelbaum (1939) and Phillips (1939) were overlooked. Working independently, these authors had established that at scotopic threshold, individual variability was evident. Phillips (1939) also noted intra-individual variation as affected by daily fluctuations and prior exposure to sunlight. The wartime studies of the British workers were summarized by Pirenne *et al.*, in 1957 and by Harvey in 1970. The review papers of Berry (1949), Kinney (1962, 1968) and Harvey (1970) are the best sources of information on night vision studies carried out in the United States from 1939 to 1965.

B. MEASURABLE PARAMETERS OF DARK ADAPTATION AND NIGHT VISION

1. Measurement Techniques

The necessity for accurate assessment of visual sensitivity has led to the development of various quantitative and qualitative methods for measuring dark adaptation. Historically, the psychophysical methods were developed first; electrical and optical methods were developed later. These methods have been utilized for both experimental and clinical purposes (Carr and Gouras, 1966; Jayle *et al.*, 1959; Pirenne, 1962b). Considerable confusion has resulted from attempts at direct comparison of the changes in visual sensitivity with these different methods. These difficulties arise mainly from differences in methodology (Jayle *et al.*, 1959).

The sensitivity of the eye to light depends upon several interrelated vital factors utilized as experimental variables:

- the duration of exposure to the critical levels of illumination;
- the mean luminance of pretest exposures;
- the duration of the test exposure;
- the size, shape, and contrast of the test object;
- the region (size and shape) of the retina stimulated;
- the spectrum of the preexposure and test exposure lights; and
- the general physiological state and psychological condition of the test subject.

Thus the conclusions from investigations in this field must be interpreted with care as it is often difficult to predict the

dark adaptation rate or final visual threshold from one set of experimental conditions.

Numerous investigative and clinical test methods for the determination of dark adaptation rate have been developed, including increment, contrast, or absolute visual threshold, as well as size and shape of the visual field and recovery of dark adaptation following exposure to photopic light levels. Many laboratories, using sophisticated techniques, have knowledgeable subjects respond to perception of altered experimental conditions. All too often, these studies include only a small number of experimental subjects.

In screening large numbers of individuals, the most frequently tested aspect of scotopic vision is the absolute light sense, i.e., the threshold of seeing. This involves either determination of the visual threshold at time intervals during the course of dark adaptation or the perception of decreasing or increasing luminance to a threshold value. The latter tests are normally 30 minutes in duration to allow for complete dark adaptation of the visual system (Jayle *et al.*, 1959). Other tests require subjects to recognize and discriminate test objects at suprathreshold levels. These tests are difficult to standardize but more closely approximate normal scotopic visual performance under low levels of fluctuating light. These tests are markedly affected by the prior visual experience of the eye as well as the spectrum, size, duration, and position of the test light (Jayle *et al.*, 1959).

Since dark adaptation involves the entire eye, including both the rod and cone systems, the psychophysical methods are affected by individual differences in ocular as well as retinal morphology and physiology. Because the response is subjective, motivation, stress, and other psychological factors may influence the final measurement. These variables are more readily controlled in the more objective measures of dark adaptation and night vision.

The electroretinogram (ERG) is the most widely used; however, the electro-oculogram (EOG) and the early receptor potential (ERP) also record electrical parameters of the eye. These electrophysiologic techniques eliminate the necessity for subjective response because they depend on evoked changes in electrical potential within the eye. These methods were developed

as clinical and research tools, and can be used to assess accurately the rate of dark adaptation and the threshold of scotopic sensitivity (Alpern, 1967a; Brown, K., 1968). There do not appear to be any published reports of extensive longitudinal studies on the dark adaptive process in a large number of subjects with these techniques.

The need for techniques to determine night vision capacity rather than dark adaptation has resulted in the development of several testing devices. These tests are employed to determine the practical ability of individuals to maintain adequate performance under reduced or negligible luminance. The Army Night Seeing Tester (ANST) was developed to measure brightness contrast sensitivity and visual acuity detail (Uhlaner and Zeidner, 1961). Although compact and portable for field use, the ANST has not been widely used. The ANST was successfully field-tested in conjunction with training for enhancement of night vision capability. Previously, several testing procedures revealed that training produced only minor enhancement of night vision (Sharp *et al.*, 1952). The Naval Medical Research Laboratory (NMRL) has developed a procedure that accurately measures night vision under field conditions (Kinney, 1962; Sweeney *et al.*, 1959). The NMRL test procedure measures scotopic sensitivity over a known area of the retina using objects of different size or brightness in several locations of the visual field.

Military utilization of the ANST, the NMRL test, as well as previously developed night vision test procedures, has been influenced by the question of the validity of night vision testing (Kinney, 1962). Originally test procedures were of questionable value because there was a lack of correlation between tests; however, these newer methods appear to test night vision sensitivity during both simple and complex tasks (Kinney, 1962). Nevertheless, the conclusion of Berry in 1949 is still valid; that is, night vision capability is too complex to be determined by any one single test.

2. Visual Acuity

Visual acuity is normally defined in terms of minimal separable distances between two targets that can be perceived, but this visual discrimination capability is exceedingly complex. Visual acuity is influenced by optical qualities, stimulus intensity, temporal retinal integrity, and neural factors in the brain. The theoretical and experimental aspects of visual acuity have been reviewed

(LeGrand, 1967b; Ogle, 1969; Pirenne, 1962c; Sloan, 1951; Willmer, 1966). A complete discussion is beyond the scope of this review. Visual acuity is not a question of whether or not a target can be discriminated. Acuity also involves the capacity to discriminate fine details in an object or scene that is viewed. Thus, acuity is normally measured in terms of angular measurement. The most commonly used is the Snellen chart. An individual is considered to have normal photopic acuity if he can resolve details of an object that creates a visual angle of 1' of arc. (An angle of 1' of arc is the angle made by a 1 inch target viewed at 100 yards; at 20 ft, the usual distance for visual acuity testing, the target is less than 1/10 inch long.) If a person can see an object of this size at 20 ft, his visual acuity is considered to be 1.0. If the individual needs a larger target for form or shape discrimination before he can identify the object at that distance, his acuity is less than 1.0. With respect to individual variation, differences in photopic visual acuity are an accepted fact and form the basis of visual defect correction, vision evaluation, and restrictive licencing procedures (Ogle, 1969; Roberts, 1967; Sorsby *et al.*, 1960).

Acuity involves one or more of at least four separate tasks: 1) detection, that is, determining whether the object is there; 2) recognition, being able to recall, or name, the object; 3) resolution, the capacity to recognize a separation between elements in a pattern; and 4) localization, the ability to detect small displacements of a part of the object, such as a seemingly vertical line whose top half slants obliquely (LeGrand, 1967a, 1967b). Obviously, physiological factors in the retina as well as neurological factors within the higher cortical centers affect visual acuity. It is generally agreed that the fundamental basis of acuity resides in the retinal mosaic or spatial separation of rods and cones within the retina.

The relationship between visual acuity and stimulus luminance level is well known (Ogle, 1969). Under mesopic and photopic conditions, visual acuity increases in almost direct proportion to the logarithm of the luminance. However, under scotopic conditions, visual acuity is extremely insensitive and increases only slowly as luminance levels are raised from absolute light sense (final threshold) to the transition zone (0.01 millilambert) (Morris and Dimmick, 1950). As dark adaptation progresses, the level of visual acuity increases. Similarly, for each reduction in

luminance level during dark adaptation, visual acuity reaches a relatively steady level with time.

Individual differences and the range of normal visual acuity are well documented for photopic vision, but less well established for scotopic vision. Visual acuity data on "average" United States citizens are readily available (Roberts, 1967). Jayle *et al.*, (1959) reviewed the scotopic visual acuity literature and concluded the subject required additional study. Recently, Burg (1966, 1967b, 1968b) and Guedry (1968) have noted relatively wide ranges of dynamic visual acuity at relatively low photopic luminance levels. Similar investigations at scotopic and mesopic levels would be useful in establishing the extent of individual differences in normal subjects (Morris and Dimmick, 1950).

The generally accepted duplicity theory of vision holds that scotopic vision involves rod receptors, and photopic vision, the cone receptors. However, there is some evidence that both types of photoreceptors are active over a wide range of luminance levels. For example, Brown (1966) has shown that the dark adapted eye employs predominantly rods, but that some cone function is involved in visual acuity functions. Thus, he concluded that the dark adapted eye uses mixed rod-cone populations, depending on the visual task and the luminance of the target and background. These observations and those of Baumgardt (1966) suggest that scotopic vision is not rod vision exclusively, and that cones may contribute to visual perception in the dark adapted eye.

The complex nature of the relationship between luminance and visual acuity at low luminance levels had led to several theoretical explanations and numerous measurement techniques (Baker, 1968; Ogle, 1969; Pirenne, 1962c). These uncertainties nullify in part the true meaning of data collected from populations of normal individuals. As noted previously, the relatively lower visual acuity associated with scotopic vision and the attendant difficulties associated with scotopic acuity testing led earlier investigators to study other more easily quantifiable parameters of dark adaptation and night vision. One of the more critical investigations revealing individual differences in scotopic acuity is that of Morris and Dimmick (1950). Using a grid target and presentation at a small visual angle, they observed acuity thresholds in six subjects that ranged from 3.7 log $\mu\mu$L to 6.7 log $\mu\mu$L. These investigators noted that at the scotopic levels tested, individual

differences in acuity were correlated with pupillary diameter changes.

Techniques that measure recovery of dark adaptation, visual field search under low luminance levels, or other scotopic visual performance tests do involve visual acuity. Many of these techniques can be used to study individual differences, but most of these tests are not evaluating scotopic acuity in terms of statistical probability of perceiving the minimal distance or size separating two targets.

3. Recovery of Dark Adaptation

Adaptometers can be used to measure increasing retinal sensitivity as dark adaptation proceeds or to measure brightness perception with increasing or decreasing background luminances. These tests can measure threshold recovery rate or arbitrary threshold levels in the scotopic or mesopic range following loss of dark adaptation.

Recovery of increased retinal sensitivity following brief exposure to photopic or very bright levels of luminance provides such a measurable parameter of night vision capability. These techniques record time to return to arbitrary threshold adaptation levels or rates of increased sensitivity following "dazzle" or "glare." Techniques to measure recovery of scotopic capability have an advantage in that they are useful in identifying those individuals who exhibit poor scotopic or mesopic capability, yet possess a "normal" dark adaptation curve as measured by their absolute light sense (Jayle *et al.*, 1959).

The photostress test of Severin *et al.* (1963) is typical of techniques that measure recovery of visual capability. The technique measures the time required to recover sufficient visual function to perform a visual task following rapid light adaptation induced by exposure to flashes of high-intensity lights. Severin *et al.* (1963) have used the photostress test to study localized retinopathies and related ophthalmologic disorders. In two tests of 57 and 40 normal patients, they observed differences in time of contrast discrimination recovery and return of visual acuity, respectively (Severin *et al.*, 1963). While data on individual differences within the experimental group and data on repeated testing of the same subject are not given, the photostress test is reproducible, is

relatively standardized, and could be useful in longitudinal studies of individual variation in adaptation recovery abilities.

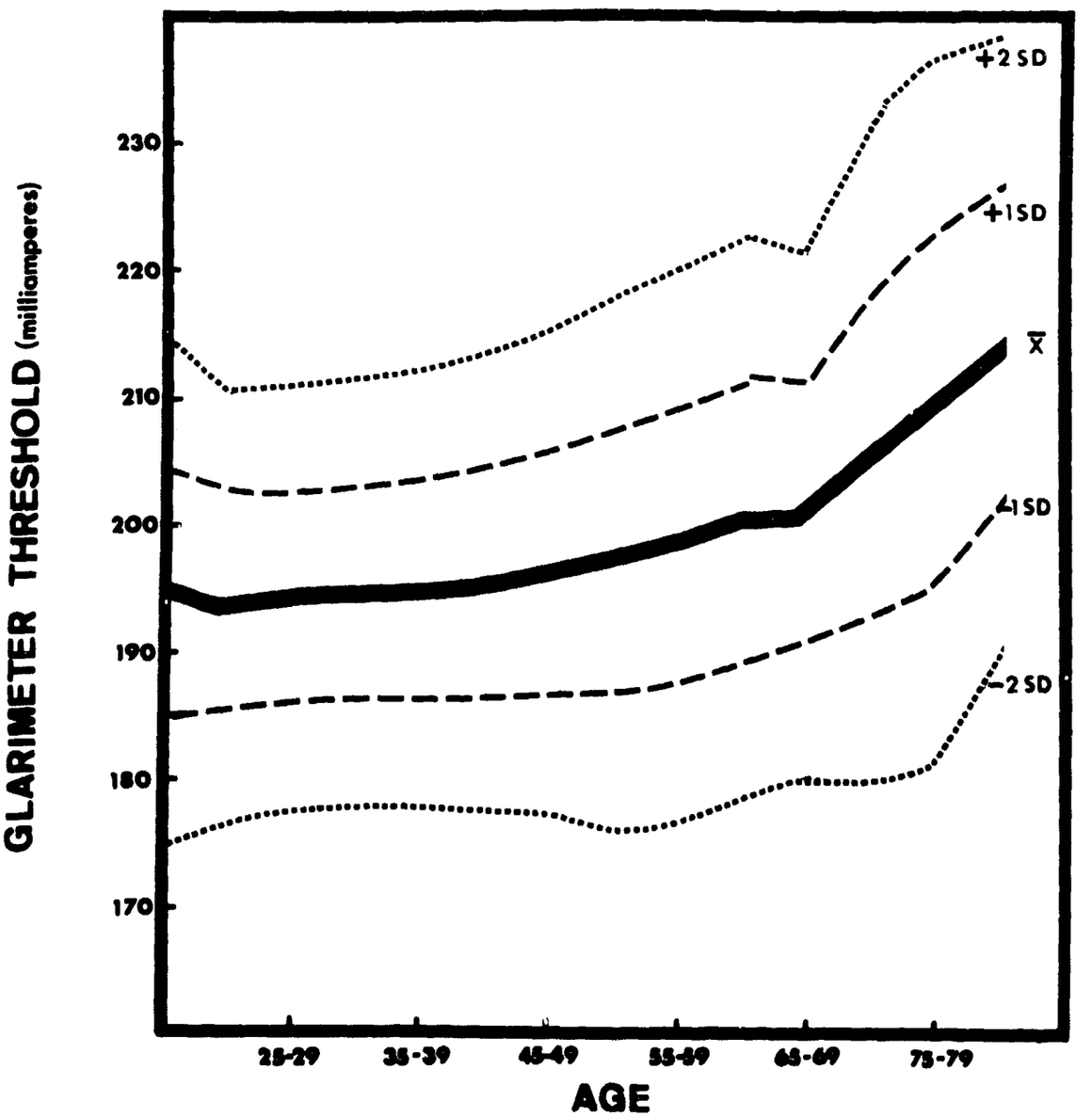
Burg (1967a, 1967b, 1968c) has recently reported on a long-term extensive study of visual performance and driving habit characteristics of 17,500 volunteer California driver's licence applicants. These studies included a glarimeter threshold test; that is, the amount of illumination required to perceive a target consisting of several shapes, and a glare recovery time test; a test of the time span required to perceive an object after exposure to "glare."

Burg concluded that there is a progressive increase in glarimeter threshold level required for target detection as age increases. Similarly, glare recovery time is significantly correlated with increasing age, with the exception that performance is relatively stable in both male and female subjects, age 25 to 40. These observations are consistent with previous studies of decreasing visual performance capacity with advancing age (Domey *et al.*, 1960b; McFarland *et al.*, 1960).

Reanalysis of data from the study by Burg (1967a) provides additional insight into the range of individual variability in glarimeter threshold (Figure 1) and glare recovery time (Figure 2). The influence of age is readily seen; however, the relatively broad range of 1 and 2 standard deviations denotes individual differences among the 17,500 experimental subjects. Burg (1967a), in commenting on the relatively large standard deviations in the glare recovery time, suggested that both experimental error and subject variability were present. Nevertheless, the relative constancy of size of the standard deviations with more accurately quantifiable glarimeter threshold level over the total age span of the male subjects, suggests the variation in this population of normal individuals is real and not experimental error alone.

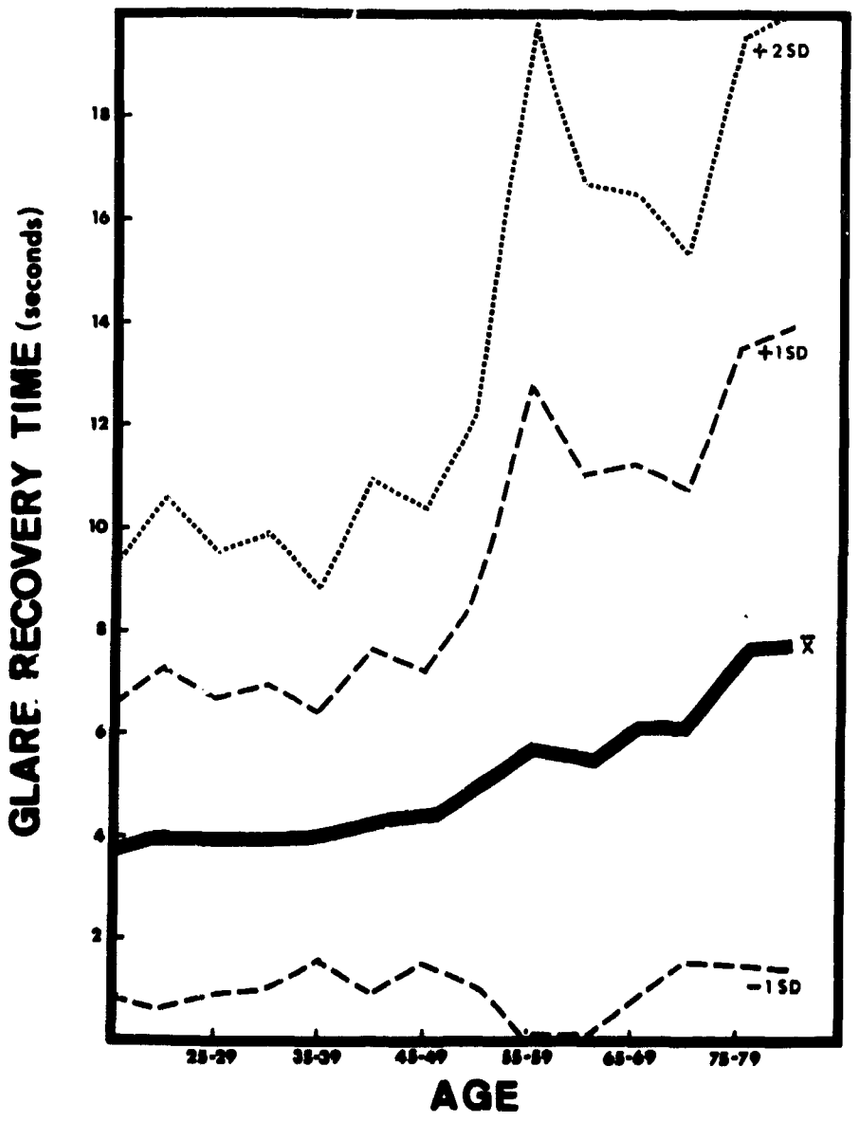
The luminance levels in these visual tests were in the range of 0.045 - 0.17 millilambert (Burg, 1967a). These luminance levels are in the mesopic range or transition zone between complete rod (scotopic) and normal cone (photopic) vision. Burg (1967a) noted that experimental constraints (time and number of subjects) did not permit a longer period of dark adaptation and that, had the subjects been more dark adapted, the glarimeter performance tests

FIGURE 1



Glarimeter threshold of 10,737 men. Threshold values in milliamperes are equivalent to threshold luminances of 0.045 to 0.170 millilamberts. (Data from Burg, 1967a).

FIGURE 2



Glare recovery time to visual threshold (0.045 to 0.170 millilamberts) for 10,694 men. (Data from Burg, 1968b).

might have been more highly correlated with age. While this is probably correct, the range of individual variability in glarimeter threshold and rate of recovery observed in these studies more realistically reflects individual differences in mesopic visual capability. Thus, these data reveal significant variation in mesopic vision and support the concept of meaningful differences among individuals with respect to visual ability under low or fluctuating levels of ambient illumination.

It is of interest to note that the provisional standards on visual factors in automobile driving prepared by the Committee on Medical Aspects of Automotive Safety of the American Medical Association (1969) do not include night vision testing. In referring to visual functions affecting night-time driving, the Committee indicated that these functions are not concerned with absolute minimal thresholds of scotopic vision, but rather are concerned with vision under low or variable illumination under twilight or mesopic conditions. The Committee concluded that three measurable mesopic functions; namely, night vision under progressively reduced illumination, glare tolerance, and glare recovery can be measured. Further, the Committee stated that there appeared to be no need to measure absolute scotopic threshold as this measurement does not indicate capacity to see under low illumination with minimal acuity or recovery from glare. They noted that testing procedures are generally empirical and results are often not reproducible. The majority of driver visual examinations, including military driving tests, throughout the United States do not quantify night vision, glare tolerance, or glare recovery.

The Committee concluded that reliable, reproducible, and economical equipment for such testing should be a part of normal driver licencing procedures. But, for the present, it appeared more convenient to rely upon structural alterations within the eye that are known to impair mesopic functioning. These include corneal opacities, lens opacities, pigmentary degeneration of the retina, optic atrophy, macular degeneration, arteriosclerotic retinopathy, and diabetic retinopathy. It should be noted that the Department of the Army Standards for Medical Fitness (AR 40-501) (1960) and the visual standards for United States astronauts (Allen *et al.*, 1970) do not specify a standard for night vision ability beyond disqualification for night blindness. In both cases, the term, night blindness, is not adequately defined.

The magnitude of this problem is evident when viewed in relation to the number of people killed or injured in automobile accidents since 1950. More injury and fatal automobile accidents occur during nighttime, between 6 p.m. and 6 a.m., than during the daytime, from 6 a.m. to 6 p.m. (U.S. Bur. Census, 1969). These figures are adjusted on the basis of total miles driven, and thus the importance of minimal standards for night vision in the comparatively simple task of driving an automotive vehicle becomes ever more critical. The same may be true for performance of military tasks at night. For example, Kennedy and Berghage (1965) observed the nighttime accident rate for carrier landings is five times the average daylight hour rate.

Burg (1967a, 1967b, 1968c) concluded that there is a definite need for accurate, reliable, and easily administered tests of night vision that should be included in vision screening programs for driver's licence applicants. He suggested that the test should include threshold and glare recovery measurements at a minimum, and, if possible, form recognition and visual acuity testing under both static and dynamic conditions with low levels of illumination. This recommendation was specifically promulgated with respect to the relationship between night vision capacity and age, i.e., older drivers should be tested more frequently to ascertain the level of visual impairment. Burg (1967a, 1967b, 1968c) suggested that one of the practical applications of this study would be restrictive licencing of applicants that had poor glare recovery or low-illumination vision.

4. Rate of Dark Adaptation

The necessity for accurate assessment of visual sensitivity has led to the development of various quantitative and qualitative methods for measuring dark adaptation. Considerable confusion has resulted from attempts at direct comparison of the changes in visual sensitivity recorded by different methods because the sensitivity of the eye to light depends upon several interrelated critical factors used as experimental variables (Baker, 1968).

Since dark adaptation involves the entire eye, including both the rod and cone systems, the psychophysical methods are affected by individual differences in ocular as well as retinal morphology and physiology. Thus, studies on the normal range of dark

adaptation or night vision capacity often report only one parameter or variable of the complex process of adaptation and scotopic vision. To date, there does not appear to have been any attempt to bring together a discussion of the individual variability of each sequential process in dark adaptation. Indeed, most studies on relatively large numbers of subjects were performed prior to the elucidation of the several processes involved in dark adaptation. Pretest exposure to light (Mote, 1955) and age of the subject (McFarland, 1962; Wolf, 1962) are variables that have been overlooked frequently.

It is now established that dark adaptation involves anatomic, biochemical, and neurophysiologic changes. The regeneration of rhodopsin is usually considered the most critical process. In both rod and cone cells, the photosensitive pigments regenerate in the dark, but the increase in pigment is insufficient to account for the total decrease in threshold of sensitivity to light. Dark adaptation is not simply the reversal of light adaptation; two distinct phases in sensitivity gain can be observed. The rapid phase has been termed the neural adaptation phase; the slower phase, photochemical dark adaptation. The rapid phase is thought to be the reverse of the swift loss of sensitivity which occurs during light adaptation. Dark adaptation of the cones occurs initially, followed by increased sensitivity of rod cells in the lowered luminance. The logarithm of the threshold value, not the threshold value itself, depends upon the concentration of the visual pigment.

Dark adaptation is rapid until the rods are adapted to luminance levels where significant photolysis of rhodopsin has occurred. At this point, rhodopsin concentration has a controlling effect upon dark adaptation. Thus, the slower phase of dark adaptation is closely related to the regeneration of rhodopsin. Since only the slow phase of dark adaptation appears to be directly related to the concentration of rhodopsin, a signal, or feedback mechanism that indicates the amount of rhodopsin present, is thought to originate in the retina. These and other observations suggest that the mechanism of adaptation must include "summation pools." Evidence from studies of several vertebrate visual systems supports the concept of summation pools in a sensitivity gain mechanism. However, neurophysiological evidence from the human eye supporting this hypothesis is incomplete.

Several recent studies on the rate of dark adaptation have utilized direct or indirect measures of changes in rhodopsin

content of the photoreceptive cells. To date, no extensive studies on a large number of normal subjects has been published. It is doubtful whether such studies would be worthwhile with respect to establishing individual differences in scotopic ability. The large number of rod cells, the position of the retina tested, and the neurologic summation phenomenon would probably negate any effects of variations in rod cell rhodopsin content.

Technical summaries of the various test methods for measuring dark adaptation have been prepared by Harvey (1970) and Jayle *et al.* (1959). As noted by Jayle *et al.* (1959), measurement of dark adaptation must take into account all the variable factors that affect the subject and the test method. The most frequently used methods are modification of techniques that measure absolute light sense. These techniques record relative threshold of vision during a period of dark adaptation, measure final threshold of vision after 30-45 minutes in the dark, or require verbal or electrical response to the subject's perception of a target in a field of continuously decreasing light levels during the course of dark adaptation.

The majority of the available data on individual variability has come from studies of the relative or absolute threshold, i.e., the absolute light sense. However, other tests have been developed that measure mesopic and scotopic visual capability. These latter techniques include the ANST, the NMRL test, and various dynamic visual acuity and glare recovery tests. These tests which have been useful in revealing individual differences are reviewed in the following paragraphs.

5. Absolute Light Sense

The absolute light sense is the most fundamental and the most frequently measured parameter of dark adaptation. Historically, the absolute, minimal, contrast, or relative brightness thresholds have been used as the criteria of individual night vision ability. Pirenne (1962a) has reviewed the theoretical basis of the threshold concept. Jayle *et al.* (1959) and Harvey (1970) have reviewed techniques of night vision testing with the various adaptometers.

The concept of "threshold" does not imply an accurately quantifiable light intensity level; it is based upon the

probability of seeing a stimulus. In this sense, threshold is an expression of statistical probability. There is no one light intensity level above which the stimulus is always seen and below which it is never seen. The range of uncertainty at any threshold is due to fluctuations in the physical aspects of the stimulus and the environment, as well as biologic variation in the individual's receptor system. Threshold values are usually expressed in terms of 50% or 90% probability of being seen. Test conditions and threshold criteria must be known if comparisons of data from several studies are carried out. The practical considerations involved in threshold measurements have been discussed previously (see p 24).

The absolute light sense, or absolute (final) threshold, may be determined by a) presenting a large test field for several seconds and noting light perception; b) presenting a point source or small field of small visual diameter for several seconds and measuring time or radiant flux over time from stimulus activation to perception; or c) with the eye fixation point controlled, presenting a point source of light for brief periods (milliseconds or less). This latter technique is useful in mapping of the peripheral visual field and determination of minimal radiant energy levels that can evoke visual sensation. For the most part, these techniques are psychophysical in that they require the subject's response to a change in experimental conditions.

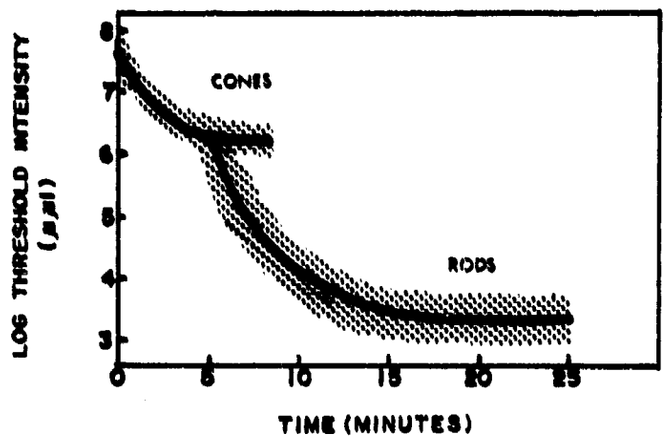
Contrast thresholds at various scotopic, mesopic, and photopic levels can be determined with similar techniques. In these test situations, the subject is required to discriminate differences between target and background luminance under various conditions — the smaller the perceived difference, the more sensitive the eye. Repetitive testing at increasing or decreasing background luminance levels establishes a family of curves that describes threshold changes over a wide range of light intensity. It is generally recognized that decreasing background luminance is less rapidly recognized than increases in background luminance. Thus, contrast threshold determinations are affected by test methodology (Boynton and Miller, 1963). The techniques used by Boynton and Miller (1963) would be useful in establishing the extent of contrast threshold variability at mesopic luminance levels. Brown (1966) has reviewed the theoretical aspects of techniques that measure visual sensitivity at supra-threshold levels.

Early studies on night vision capability used final threshold as a criterion of individual variation. Hecht and Mandelbaum (1939) conducted the earliest definitive investigation of normal variation in scotopic threshold values. Although previous investigators had noted differences, these investigators observed the course of dark adaptation in 110 normal subjects and reported both the mean and range of these data. In Figure 3, the stippled area includes the data from 93% of the population in the cone-mediated portion of the curve and data from 80% of the rod-mediated section of the curve. They concluded that ±0.7 log unit was the average normal range of inter-individual threshold variation during dark adaptation. Similar data were collected by McFarland *et al.*, 1939).

Hecht and Mandelbaum (1939) also reported intra-individual threshold variation during dark adaptation of 0.3 log unit from day to day in six subjects over a four-week period. These observations on inter- and intra-individual differences are the most frequently cited data on normal variation. Subsequent studies, using similar or other threshold measurement techniques, have confirmed the validity of these values. Wolf *et al.* (1960) observed a similar variability of 0.3 log unit during dark adaptation in three subjects tested over an eleven-month period. These investigators found the greatest range of variability in the transition zone from photopic to scotopic vision. This conclusion is consistent with the observations of Kinney (1968) on mesopic thresholds and the results of Campbell and Rittler (1969). Using filters to separate cone from rod function, they found a greater variability in rod function than in cone function at final threshold. The range of variability increased with distance from the fovea (Campbell and Rittler, 1969). This difference in range of variation is also evident in the data collected by Hecht and Mandelbaum (1939).

In another early study of threshold variation in normal males, Sheard (1944) observed that approximately 2% showed abnormally high dark adaptation thresholds. Analysis of the dark adaptation thresholds of a group of 45 pilots revealed the normal variation in final threshold was ±0.5 to 0.7 log unit. Hecht and Mandelbaum (1939) had postulated that intra-individual differences were least in a well trained subject when the environment and the test procedures were carefully controlled. In these tests, Sheard (1944) was able to reproduce dark adaptation threshold values on the same subject from day to day within 0.1 log unit.

FIGURE 3



Mean and range of threshold intensity for 110 normal subjects during dark adaptation. (Modified from Hecht and Mandelbaum, 1939).

In 1950, Blackwell and Verplanck reported extensive studies on the apparent day to day fluctuation in night vision thresholds observed with several night vision test techniques. Using random forced-choice responses (seeing or not seeing), they concluded that no large-scale day to day changes were present, and that chance alone could explain much of the data variations beyond normal limits. In addition, Blackwell (1950) concluded that the laboratory-observed, short-term variation would not negate the validity of practical tests of night vision thresholds. However, he pointed out that other physical and psychological variables (i.e., motivation, discomfort, fatigue) could affect the value of threshold determinations.

Previously, Blackwell (1946) had reported on contrast thresholds of highly trained normal individuals and had noted the role of light intensity, stimulus area, and threshold contrast. The average individual deviation over several years was ±12% and ranged up to 40%.

The range of dark adaptation thresholds was reported by Sloan (1947) in a group of 101 normal individuals. The change of dark adaptation thresholds was followed over a 40-minute period. The distribution of the individual thresholds at each determination showed close agreement with the theoretical normal distribution curve; 68% fell within 1 standard deviation of the normal curve, 95% within 2 standard deviations, and 99.7% within 3 standard deviations. Dark adaptation thresholds of individuals beyond ±2 standard deviations were considered beyond the normal range; only 5% of the subjects were in this category. As expected, increase in dark adaptation threshold occurred with increasing age. In discussing these observations, Sloan (1947) pointed out that measurement of the normal deviation of an individual's variation in dark adaptation threshold requires rigidly standardized methodology and experienced test subjects as it is possible for a person whose final visual threshold is close to the lower limit of "normal" to have an increase in threshold of as much as 1.0 log unit above his own normal level, and still be within the group "normal" range. While the experimental methods differed greatly from that of Sloan, Pirenne *et al.* (1957) measured the absolute threshold values of 22 young subjects and reported essentially similar data.

More recently, Hallett (1969b) has reinvestigated the range of both day to day and task to task variability using the methods

previously described by Pirenne *et al.* (1957). Hallett attempted to relate the observed variation in absolute and contrast thresholds to some physiologic basis. He concluded, as did Blackwell previously, that day to day changes in threshold within an individual do occur, but this drift in threshold of seeing is a reflection of observer change in criteria of seeing or minor changes in viewing conditions. Hallett (1969b) was not able to relate the threshold value fluctuations to either the dark light of the retina as suggested by Barlow (1964) and Barlow and Sparrock (1964) or the filter factor proposed by Pirenne *et al.* (1957).

However, Hallett (1969b) does make an important point that the range of inter-individual variation reported by numerous other studies (Hecht and Mandelbaum, 1939; Pirenne, 1962a; Pirenne *et al.*, 1957; Sheard, 1944; Sloan, 1947; Stigmar, 1970) may be misleading because the mean threshold value of each individual was not calculated. Because the threshold value does drift, only the mean value would represent the most critical approximation of each individual's actual minimum absolute light sense. Thus it would appear that differences in absolute light sense among individuals are grossly larger than those observed in previous studies and that within inter-individual variation, the magnitude and effect of intra-individual variation remain to be determined (Hallet, 1969b).

The utility of the absolute threshold determination as a practical measure in estimating night vision capacity has been questioned repeatedly (Boynton and Miller, 1963; Brown, 1966; Pirenne *et al.*, 1957). Fundamental differences exist between experimental laboratory studies that measure light threshold of the fully dark adapted eye under controlled conditions, and life situations that require efficient vision in an environment with changing levels of illumination. Normally, the eye must continually accommodate to the visual demands of changing environmental luminance levels (McFarland and Domey, 1958). For these reasons, an important distinction can be made between the night vision efficiency of the soldier, as measured in test situations, and his rate of adaptation under the more realistic demands of an albeit low, but fluctuating, ambient light level during field operations.

Pirenne *et al.* (1957) measured not only absolute thresholds, but also relatively complex visual tasks at luminance levels up to the mesopic range. They confirmed the observation of

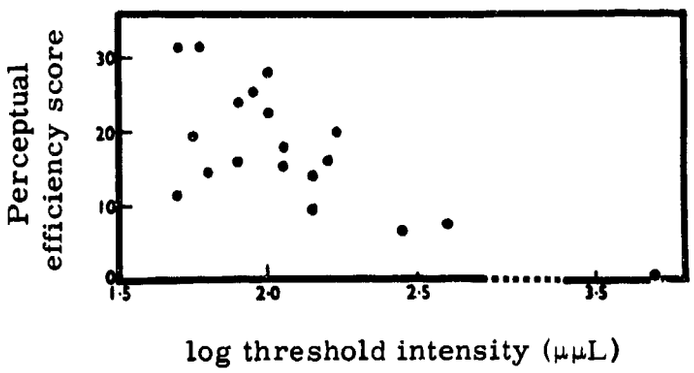
previous investigators that absolute threshold was a useful prediction of the threshold of visual acuity. Pirenne *et al.* (1957) postulated individual differences at absolute and supra-threshold levels were related to variations in individual requirements for stimulus light levels. As noted previously, the filter factor hypothesis of Pirenne *et al.* (1957) requires further explanation and study. However, the data on individual efficiency of seeing reported in the study by Pirenne *et al.* (1957) exhibit a wide range of dispersion even when the absolute thresholds of the subjects are quite similar (Figure 4).

Numerous investigators have shown that the zone of maximum scotopic sensitivity is 10^{o} to 20^{o} outside the foveal area. Using different tests, Meur (1965) and Dall'era and Brancato (1968) demonstrated that the area of maximum sensitivity is itself a variable characteristic among normal males. Results from the NMRL test are, in part, a reflection of this variability.

Kinney *et al.* (1960b) used the NMRL test to determine individual variations in the total visual field sensitivity in two groups of ostensibly normal enlisted men (Figure 5). The NMRL test measures scotopic sensitivity over a known area of the retina using targets of differing size in several locations throughout the visual field. These data indicate that there is a normal distribution of scotopic sensitivity in these young men. In a review of night vision testing methodology, Kinney (1962) acknowledging the inter-individual variability and the seasonal variation in individuals, concluded that techniques such as the NMRL test could provide valid data on night vision capacity. Efficient performance of tasks requiring night vision was thought to be a function of the visual system sensitivity and, if identified, such individuals could be trained to use their capacity even more efficiently (Kinney, 1962).

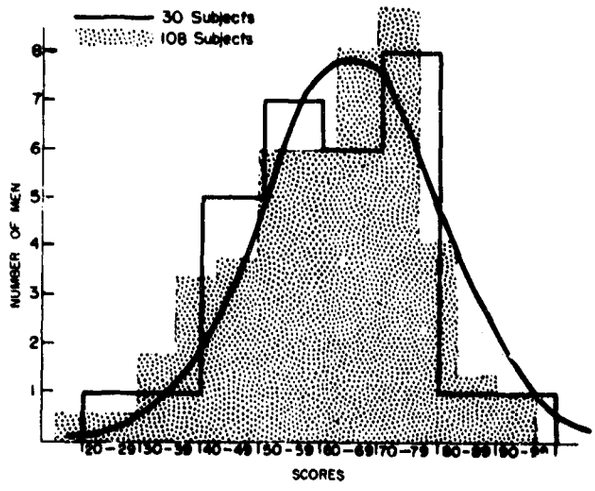
In 1968, Kinney reported on additional investigations with the NMRL test and a mesopic acuity test analogous to the ANST. Subjects were tested for photopic, mesopic, and scotopic visual sensitivity, in that order. The test parameter was basically a target form recognition task at decreasing background luminance levels (acuity contrast thresholds). Frequency distributions of the 100 test subjects at three standardized scotopic luminance levels show a relatively wide range of values (Figure 6). In each case, the data are skewed on the low side which is characteristic of visual functions. Analysis of scores from the 20 highest

FIGURE 4



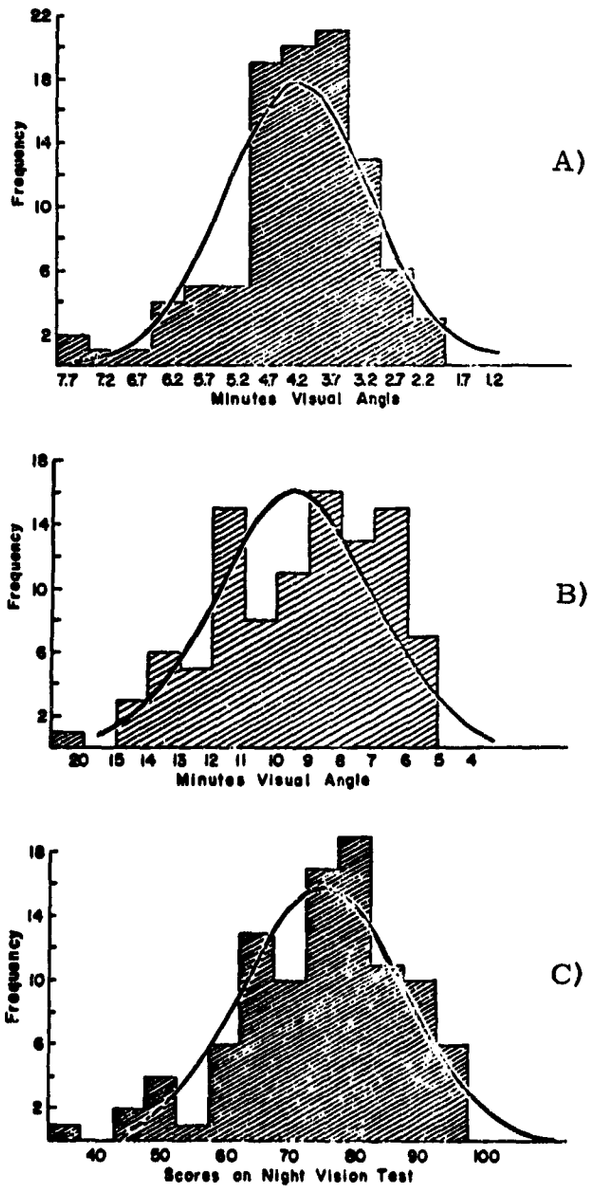
Dispersion of perceptual efficiency scores (seeing versus not seeing) for 22 normal subjects with closely related absolute visual threshold values. (Modified from Kinney, 1962; originally from Pirenne *et al.*, 1957).

FIGURE 5



Distribution of scotopic sensitivity test scores (NMRL test) for two samples of normal young men. (Units on vertical axis refer to the smaller sample). (From Kinney, 1962; originally from Sweeney *et al.*, 1959. Reproduced with permission).

FIGURE 6



Frequency distribution of visual acuity in a mesopic-scotopic threshold task for 100 subjects, in terms of minutes of visual angle at luminance levels of: a) 6.7 log μμL, b) 6.0 log μμL, and C) in terms of NMRL test scores at 5.5 log μμL. (From Kinney, 1968. Reproduced with permission).

and 20 lowest subjects revealed that for equivalent visual acuity at the highest luminance level, the average subject needs twice the light intensity required by the best subject; at a level of 6.0 log $\mu\mu$L, the subject with the least acuity requires 10 times the light needed by the average subject. At the lowest scotopic luminance level, the most sensitive observer is 2.6 times as efficient as the least sensitive normal subject. In practical terms, Kinney (1960a) stated that the least sensitive man could see a 100 candle power beacon at 12 miles, while the most sensitive person could see the same light at 18 miles.

As noted in numerous previous investigations, mesopic and scotopic visual ability are not correlated. Kinney (1968) did point out sizable individual differences in night vision capacity at both scotopic and mesopic light levels. In addition, she concluded that the techniques of night vision testing employed in these studies were reliable, could identify the differences between individuals, and were useful predictors of night vision performance in field situations.

Rendahl (1969a) has utilized the Beyne scotoptometer to determine the range of night vision ability in 1654 young (18-year-old) Swedish conscripts. Frequency distribution of the data exhibits normal dispersion with a slightly skewed pattern for the data from most sensitive subjects. Rendahl reported that results with both the ANST and the NMRL test were correlated with the above observations. Rendahl (1969b) is extending these studies of individual variation to a large population (50,000) of young Swedish men.

Various types of congenital color blindness and bilateral macular degeneration are known that affect absolute light sense; in these individuals cone function is partially or completely lost, but normal rod function is retained. These dysfunctions of the visual process may occur to some degree in a relatively large number of individuals (Berry, 1949; Sheard, 1944; Sloan, 1947). Presumably, such individuals would be identified and eliminated at induction or during subsequent screening for critical military duties.

C. RECENT APPLICATIONS OF NIGHT VISION TESTING TO PERFORMANCE OF MILITARY TASKS

Numerous investigations on recovery of dark adaptation have documented the progressive decrease in visual sensitivity occurring with aging. It is obvious that, in general, the data support the long-standing empirical observations that mesopic visual abilities are best in younger soldiers. But more importantly, these studies suggest that within all age groups the normal variation among individuals is sufficiently large to affect performance of military tasks carried out under darkness. The validity of this conclusion has not been firmly established; however, recent research on human factors in efficiency of night vision device use suggests that such a conclusion is relevant to developing concepts of tactical capability (Richardson, 1968; U.S. Army Combat Develop. Comm., 1968).

An ongoing Army behavioral research program has been developed that is concerned with human factors affecting use of sensory aids in continuous operations (Hyman and Sternberg, 1969; Hyman *et al.*, 1970; Sternberg, 1970). Recent studies have involved techniques for search and target acquisition with and without various night vision devices. In one series of experiments, Sternberg and Banks (1970) noted considerable variability in target detection among individuals using several night vision devices under differing ambient light levels (starlight to full moon). It should be noted that the output of the various night vision devices is in the upper mesopic to photopic range of visual adaptation; however, certain experiments in this research program were conducted in the dark where visual activities other than actual use of the night vision device involved partial or complete dark adaptation (Sternberg and Banks, 1970).

Easley *et al.* (1969) investigated the effects of interruption of dark adaptation on performance of two military tasks. Dark adaptation was interrupted by exposure to a photopic level of luminance by use of a simulated image intensifier. While individual differences in task performance were not always statistically significant, the mean and standard deviation on NMRL test scores on the 71 test subjects suggests considerable variation in individual responses to use of the simulated night vision device. This hypothesis is supported by the tentative conclusions of Woodside and Dixon (1970) on user beliefs as to the attributes of two image intensifying night vision devices.

Stewart *et al.* (1968) reported drug induced partial night blindness (miosis) raised the scotopic threshold of each of 10 volunteer subjects. However, he noted that threshold values in both untreated and treated eyes exhibited considerable variability. Stewart (1970) has recently extended these studies to include the deleterious effects of miosis on performance of military tasks at night.

In another study, Vicino (1970) reported target acquisition performance of artillery and mortar observers. Vicino studied the performance of the observers using unaided night vision alone. He noted that each subject approaches the target detection task with highly individualistic sensory skills, training, and intelligence. These characteristics will affect the extent and direction of his performance. Prior to measuring target acquisition performance, all subjects were given a basic visual skills test, an auditory examination, and a battery of visual search behavior tests. The NMRL test was used to assess their night vision sensitivity.

Vicino (1970) found that night vision test scores were highly correlated with target detection time. Similarly, visual area search efficiency scores were correlated with target detection time. He concluded that individual differences in several human characteristics including training, skills, and abilities contribute significantly to observer acquisition performance.

Studies of this type are specifically relevant to the understanding of performance of military tasks where night vision abilities are critical. Vicino (1970) presented these data in graphs of frequency distribution of subject score for each of the several human factors studied. Scores for tests of visual area search, night vision, concealed figure detection, intelligence, and several behavioral measures all show normal or skewed distribution curves. The use of this technique for data presentation makes individual variation a clearly identifiable component in the presentation of experimental results. Had data from numerous studies conducted since World War II been presented in terms of frequency distribution, the influence of individual variation in night vision capability would not be so obscure.

Hopkins (1970) has recently reviewed the role of individual differences in performance efficiency of the individual as a component of a man-machine system. While night vision variability is not discussed in detail, Hopkins (1970) commented that human factors are usually focused on the extent to which individuals differ in a single measurable trait. The relative score of the individual with respect to that dimension is then correlated with task performance. He suggests that analysis of many such correlations may permit formulation of methods for improving man-machine system efficiency. These techniques could be useful in furthering understanding of the ability of the soldier to see at night and his performance of military tasks.

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V. INTERNAL FACTORS INDIRECTLY AFFECTING VARIABILITY IN SCOTOPIC VISION

A. GENETIC FACTORS

The inherent variability of measurable parameters of night vision ability is an expression of the genetic information in that individual. While the early literature contains numerous references to night vision anomalies related to eye color, race, or congenital defects, only the latter appear to have a firm scientific basis.

Jayle *et al.* (1959) in their review of subjective factors that affect night vision noted that numerous authors had reported variations in dark adaptation and night vision among different racial groups. Many of the earlier studies suggested that Negroes and Japanese had superior night vision capability; however, Jayle *et al.* (1959) concluded that definitive evidence of racial differences in inherent night vision ability was not available. There is no recent evidence that contradicts this conclusion. Visual acuity data often exhibit racial, sex, and regional differences (Holmes, 1946; Nat. Cen. Health Stat., 1967). For example, uncorrected distance visual acuity of 20/100 or less is more prevalent in Caucasian United States citizens than in Negro United States citizens (Nat. Cen. Health Stat., 1967). However, evidence of a genetic basis for this difference appears minimal and environmental effects offer several logical bases for the differences. Those racial differences observed by previous investigators can be explained by test procedure deficiencies, prior learned experience, or individual differences produced by environment.

Walls (1944) had suggested previously that the apparent racial differences were similar to the differences noted between individuals with heavily pigmented, e.g., brown irides, and hazel or blue-eyed individuals. He considered the difference in melanin pigmentation a possible source of the observed differences (Walls, 1944). Jayle *et al.* (1959) concluded that the several reports of iris pigmentation and night vision ability relationships provided conflicting data. There is a need for a critical reexamination of the possible role of eye pigmentation characteristics on variation in scotopic vision.

Jayle et al. (1959) reviewed the congenital functional anomalies that involve loss of night vision capability. It is assumed that individuals with these congenital abnormalities would be excluded from military service (see p 74).

B. SOMATIC FACTORS

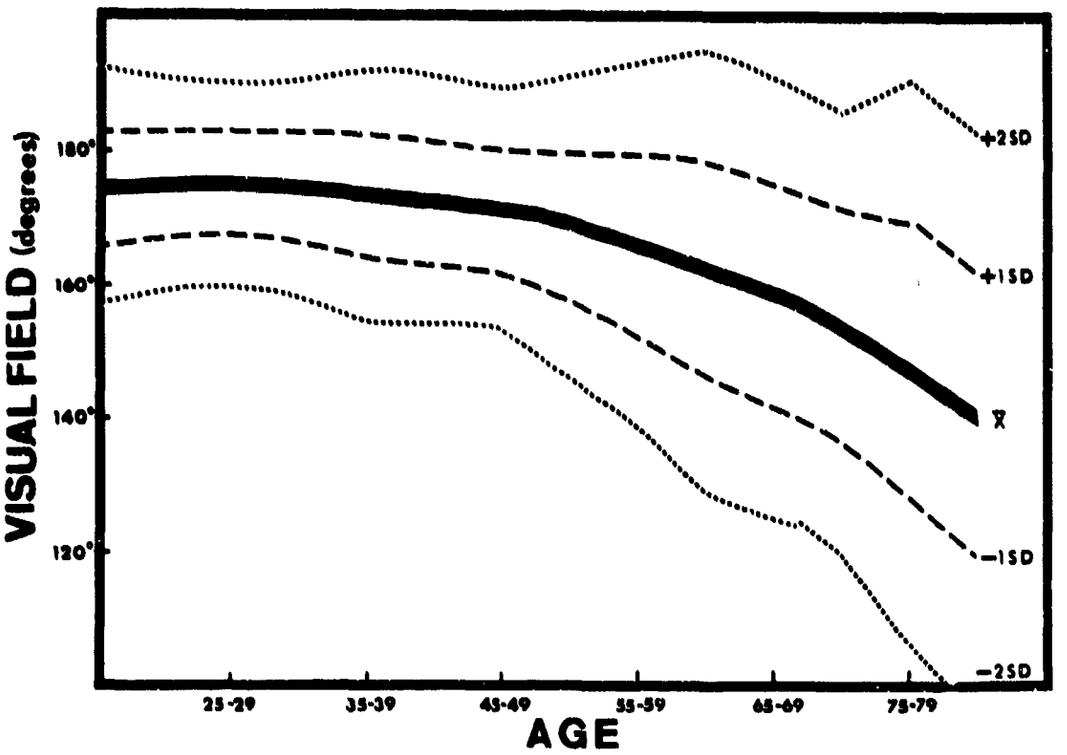
1. Anatomy

Interocular distance, orbit size, and eyeball dimensions are obviously variable characteristics of each individual human. These quantitative dimensions are important in correction of visual impairments, but are, in general, indirectly related to individual differences in dark adaptation and night vision capacity. Interocular distances and other more specific morphological characteristics show normal statistical distribution in the population (Best and Taylor, 1966; Christensen *et al.* (1969). For example, total visual field is a complex function of orbit and bridge morphology, ocular size, and pupillary and retinal factors. Burg (1968a) has recently reported on numerous characteristics of a large number of California residents. Data on total visual field is expressed as a function of age (Figure 7). These studies are consistent with generally accepted data of total visual field (Best and Taylor, 1966; Fisher, 1968). It is of interest that statistical analyses of data from the study of California drivers reveals that while the mean angle of total visual field declines with age, the range of values that embraces 95% of the normal population is relatively consistent from age 16 to age 49. These data on range of total visual field suggest that there is considerable latitude in the size of the peripheral visual field in normal males.

Nakajima *et al.* (1968) have reported recently on an extended longitudinal study of ocular dimensions in several hundred subjects in 314 family units. While total visual field or night vision were not investigated, the study provides definitive data on the heritable basis and range of normal variation in anatomical features of the eye.

More specific anatomical variation has been observed. For example, analysis of fundus photographs of 100 patients between the ages of 20 and 40 indicated that the primary arterial bifurcation was present on the discs of 174 of the 200 eyes (Christensen *et al.*, 1969). The number of arterial branches crossing the margin of the optic nerve head were also determined. The most characteristic distribution showed four arterial branches, each going to one of the four quadrants. A similar pattern was noted for veins, and the venous distribution followed the arterial distribution, but there was

FIGURE 7



Size of lateral visual field in 10, 847 men. (Data from Burg, 1968a).

considerable variation. In the statistical study of the arterial branches, Christensen *et al.* (1969) observed 61% of the eyes had four major arterial branches; 27.5% had five; and the remaining 11.5% of the eyes had either three, six, or seven vein branches. The effects of such individual differences on vision were not recorded.

The genetically determined pattern of ocular blood supply in the retina might influence the activity of rod receptor cells in the visual periphery, but the number of rod and cone cells over the retinal surface is itself a genetically determined and variable characteristic (Best and Taylor, 1966; Walls, 1944).

As with other quantitatively defined parameters of the visual system, ocular tension shows wide variation in normal subjects. Ocular tension values are measured in assessing the incidence of glaucoma. Most surveys report increased ocular tension with age and this rise is more prevalent in women. This sex difference is evident in all ages. The normal range of ocular tension is slightly skewed to increased values by the effects of age (Bankes *et al.*, 1968). In one typical survey, the mean ocular tension was 16.29 (SD ± 3.43) mm Hg, while 78% had ocular tension values between 12 - 19 mm; the normal range included values of 6 - 29 mm (Bankes *et al.*, 1968). DeVenecia and Davis (1963) have reported a diurnal pattern of variation in intraocular pressure.

The most important anatomical characteristics affecting scotopic capability are those that influence the refractive power and accommodative ability of the visual system. Assuming correction for visual deficiencies would be made, anatomical considerations would probably have a minor role in individual variation in dark adaptation and night vision.

2. Dioptric Factors

a. Refractive Power and Accommodation

The human eye has a refracting power of approximately 60 - 65 diopters. The refractive media of the eye include the surfaces and substance of the cornea, aqueous humor, crystalline lens, and vitreous humor. The refractive power is thus a composite

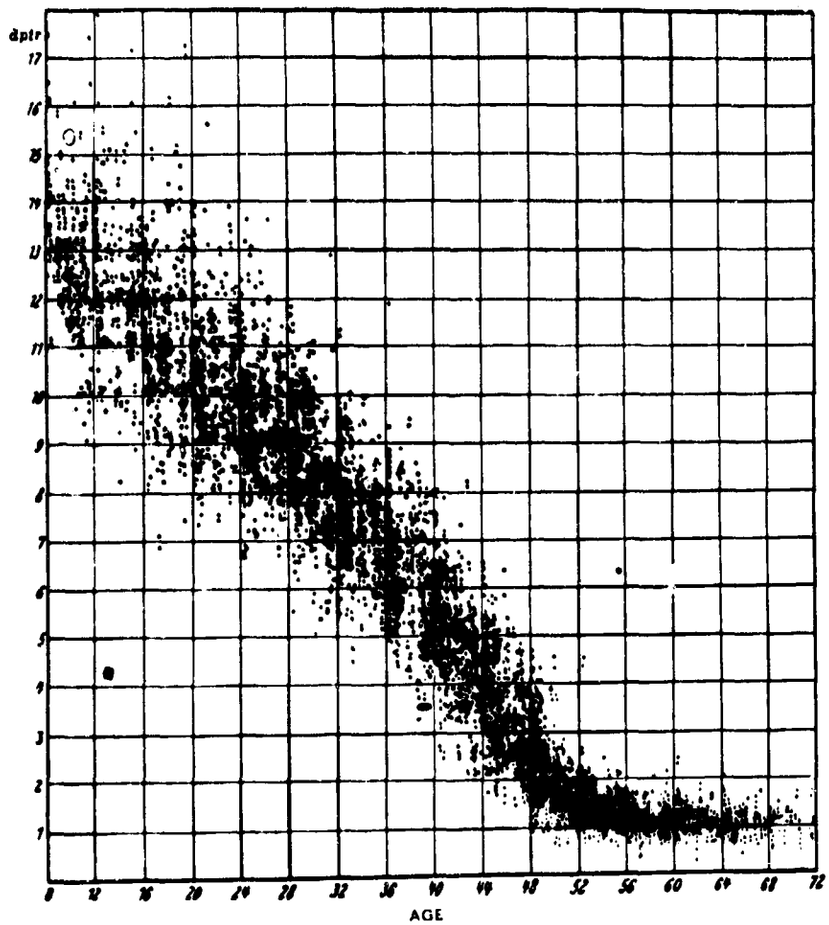
of at least six refractive surfaces, five refractive indices, and two linear distances (Hirsch, 1967). These values do vary and thus refractive capability is characterized by the sum of these individual differences.

For all practical purposes, the range of variability of the majority of these factors is within narrow limits (Hirsch, 1967); and the refractive power of the eye is primarily a function of three variables: a) the curvature of the anterior surface of the cornea; b) the axial length of the eyeball; and c) the power of the crystalline lens (Sorsby, 1967). The greatest refraction, approximately 42 diopters in the normal eye, occurs at the anterior surface of the cornea. But the ability to focus involves primarily the phenomenon of accommodation. This adjustment of ocular dioptrics involves alterations of the convexity of the crystalline lens focusing light rays from an external object on the retina. Refractive ability of the crystalline lens is approximately 19 diopters when accommodation is relaxed and up to 36 diopters with full accommodation (Best and Taylor, 1966). However, the axial length exerts the most effect upon the total refractive capacity of the eye (Van Alphen, 1961).

Axial lengths of normal eyeballs vary over an approximate range of 20 - 30 mm (Sorsby, 1964). Because a change of one mm will alter the total ocular refraction by three diopters, the range of axial diameters can result in a 30 diopter range in refraction. The anterior corneal surface varies from about 38 - 48 diopters, a range of about 10 diopters (Alpern, 1962).

The farthest point from the eye at which an object can be seen is termed the far point; similarly, the shortest distance describes the near point. The difference between the near and far points is the range of accommodation. The amplitude of accommodation is the difference between the refractive power of the eye with accommodation relaxed (focused at the far point) and its refractive power with full accommodation (focused at the near point). Both the range and amplitude of accommodation are highly variable and diminish with age (Best and Taylor, 1966). In young adolescents the amplitude of accommodation is approximately 16 diopters, 8.5 at age 30, and declines to 1 diopter at about 60 years of age (Best and Taylor, 1966; Friedenwald, 1942). At age 20, the normal range includes values from 7 to 17 diopters and, at age 30, from 5.5 to 11.5 diopters (Friedenwald, 1942) (Figure 8).

FIGURE 8



The range of accommodation of the eye (diopters). (Reprinted from Friedenwald, 1942. Copyright 1942 by the Williams and Wilkins Co. Reprinted with permission of the copyright owner).

This variability and progressive decrease with age in amplitude of accommodation is due primarily to reduced plasticity and elasticity of the crystalline lens cortex and nucleus (Best and Taylor, 1966). Also involved are diminished strength of the ciliary muscles and, usually after 60 years of age, residual accommodation is mainly associated with changes in pupillary diameter.

Individual variation in refractive capability is thus the expression of the influence of axial length, anterior corneal curvature and lens shape, respectively. However, the problem is more complex in that each of these variables is not independent; variability in one is related to variability in others. Corneal curvature and lens power are both related to axial length (Hirsch, 1967). As with any complex physiologic phenomenon, variability may be due to heredity, environment, or both. The identification of these variables within the individual and, more importantly, discerning the normal biologic variation caused by disease, physiological changes, or advancing age are of paramount importance (Dunphy, 1970).

Sorsby (1964) has recently reviewed in detail the frequency, distribution, and nature of spherical refractive errors in the normal eye. He concludes that the distribution of refractive anomalies in the population is leptokurtic, with a mean value that is slightly hyperopic. For example, in a study of 1033 British recruits, the distribution of refractive status had a range of +8 to -9 diopters, yet 75% of the sample exhibited values from 0 to +1.9 diopters (Sorsby, 1967). Sorsby considers the wide occurrence of normal vision (emmetropia) to be the result of the marked correlation of axial length, corneal curvature, lens power, and anterior chamber depth. Distribution of values for these variables computed from several studies indicated that corneal curvature, depth of the anterior chamber, and lens power show normal curves of distribution, while axial length and total ocular refraction exhibit the leptokurtic distribution skewed slightly to positive values (Sorsby, 1967).

It is generally held that emmetropia and the forms of ametropia are genetically determined and do show differences with sex and age (Alpern, 1967b; Dunphy, 1970; Sorsby, 1967). Myopia is more prevalent in women and increases with age in both sexes. Young (1961, 1963) has suggested that refractive anomalies

arise from environmental stress on the genetically determined refractive capacity. According to Young (1961, 1963), the increased myopia observed in school children, honor students in college, and other groups can be related to excessive use of near vision in reading. Van Alphen (1961) has shown that the central nervous system plays a role in the development of emmetropic and ametropic developments. The etiology and epidemiology of refractive anomalies are currently under active investigation (see Ref. No. 174, 1967).

In summary, it would appear that approximately 75% of normal young men would have ocular refractive power within the ophthalmologically normal range. Since refractive anomalies occur in one out of four inductees, the necessity of ophthalmologic examination is obvious. The effects of refractive anomalies would primarily affect photopic vision, but would secondarily influence scotopic capability.

Because night vision capacity is primarily peripheral visual ability, night vision acuity would be expected to decline with decreased accommodative capacity. Differences in accommodation among individuals and within an individual with advancing age adversely affect night vision (see p 61). Because these changes usually occur after age 40, they would not be expected to be an important factor in night vision of the young soldier, but could be a critical variable in visual ability of senior personnel.

b. Pupillary Diameter

The most apparent change in the dark adapted eye is the increased pupillary diameter. As the ambient or background light decreases, pupillary dilation allows up to a 16-fold increase in the area of exposed lens. This can account for approximately one logarithmic unit of luminance change in adaptation at both mesopic and scotopic levels. Loewenfeld (1966), in an exhaustive review of pupillary movements, concluded that the parafovea and retinal periphery had lower pupillary thresholds (higher light sensitivity) than the fovea. In the normal dark adapted eye the threshold of pupillary reaction is lowest even when very small areas are stimulated. Individual differences in reaction to a given stimulus involve both amplitude of pupillary diameter change and duration of the latent period prior to response. The former have

less variability than the latter. Loewenfeld (1966) suggested that minute or transient alterations of the physiological state of the subject are especially evident at pupillary threshold response levels. They are a measure of the autonomic nervous system balance of the individual. In addition, the motivation of the subject, fatigue, or the emotional stress of the test situation may provoke changes in pupillary response. Feinberg and Podolak (1965) have also shown individual variability in the duration of the pupil latency response time. These authors indicate that pupillary latency time varies among individuals, and increases over time in individuals. Pupil latency period has been positively correlated with increasing age by several authors (Feinberg and Podolak, 1965; Schäfer and Weale, 1970).

Morris and Dimmick (1950) have reported that pupil size varies in individuals when measured by infrared pupillometry under low ambient light. The individual differences in pupil size were positively correlated with scotopic visual acuity. While this study included only six observers, it points out that pupil size requires further study.

c. Phoria

Polishuk (1961), in a study of over 3,000 Israeli flight crew personnel found the frequency of both near and far phoria was distributed over a normal curve. Heterophoria had no relation to the success or failure of these individuals in military flight training. Burg (1968d), in a study of over 17,000 subjects ranging in age from 16 to 92, concluded that a slight but statistically significant trend toward exophoria occurs with increasing age; however, this trend is not consistent. Because the normal deviations in convergence and fusion phenomena would be expected to affect photopic as well as scotopic vision, individual variations in phoria alone are indirectly related to night vision capability of the soldier. In a review of research on strabismus and related visual defects, Breinin (1967) suggested that there is a critical need for further research on all aspects of the oculomotor system.

d. Eye Fixation

The process of extracting visual information and

storing this information conceptually consists of several sequential neurophysiologic events. The first of these is apparently the development of a visual image which persists for less than one second (Haber, 1970a; Yarbus, 1967). During the establishment of this "iconic" image the eye fixes on the object. The eye moves in saccades between fixation points in the process of vision (Haber, 1970a). This eye fixation time appears to be relatively constant. In a study of linguistically codeable stimuli, Haber (1970b) confirmed earlier studies and established that the eye fixation time was 250 ± 10 msec in 25 normal subjects. In mesopic and scotopic test situations, eye fixation time increased to an average value of 440 msec and the range also enlarged. Yarbus (1967) has reported similar values for variations in saccade duration and eye fixation time in studies of the fovea and retinal periphery. If these observations are correct, then there is very little variability among individuals in eye fixation time, eye movement time, and "iconic" image retention time. However, individual variability might be reflected by the number of eye fixation points required for cognition.

3. Age and Sex

The effect of aging is one of the better understood aspects of dark adaptation and night vision. Average night vision proficiency declines with age; the decrease is most significant in persons over 50 years old. According to McFarland and Fisher (1955) for every 13 years increase in age, the intensity of illumination must double if an object is to be seen by the fully dark adapted eye. The loss of night vision acuity, reduction in dark adaptation rate, and elevation of final threshold are believed to be related to progressive aging of the cornea, lens, retina, optic nerve tract, and the higher cortical visual perceptive processes. The relationship is curvilinear, rather than linear (Domey *et al.*, 1960a). Since dark adaptation involves several physiological processes, e.g., pupillary diameter increase, increased rod and decreased cone functioning, and neural pathway changes, a strict linear relationship would not be expected. In general the variation among individuals is more evident after age 40 - 50 (McFarland, 1962).

Jayle *et al.* (1959) note that several early investigators reported greater range of variation in final visual threshold in older

subjects. Robertson and Yudkin (1944) report a range of 1.45 log units for 69 subjects age 50 - 59, but a variation of only 1.00 log unit for 76 men age 20 - 24. Similar, but not identical ranges of variation have been reported by several investigators (Birren *et al.*, 1948; Hecht and Mandelbaum, 1939; McFarland and Fisher, 1955). Night vision of a large population of British army troops was studied by Lister and Bishop in 1943. Although this study appears to have been overlooked by subsequent investigators, the authors did screen a large population of young males for scotopic visual acuity rather than minimum threshold of seeing. Results indicate a shift in night vision capability that reflect the elevation of final threshold of dark adaptation known to occur with advancing age. However, the study had relatively few subjects over 39 years old.

While dark adaptation threshold values are highly correlated with age, the variation at final threshold is only one type of individual characteristic. Lister and Bishop (1943) pointed out that scotopic visual acuity, not minimum threshold, was of paramount significance in the military situation. They tested over 10,000 British army soldiers ages 18 - 55 for night vision acuity at levels of 3 to 24.0 micromillilamberts (Table 1). The data are normally distributed at the six luminance levels in the eleven age groups tested.

McFarland and Fisher (1955) recorded the final threshold value of 201 dark adapted subjects (Figure 9). These data suggest a range of 1.0 log unit or greater is characteristic of males from age 20 - 60, notwithstanding the continued rise in threshold level with age. According to Pinson (as quoted by McFarland and Fisher, 1955), "the trend toward a decline in average dark adaptation with age is of minor significance in comparison with individual variations in the dark adaptation proficiency."

Domey *et al.* (1960b) studied threshold and rate of dark adaptation in 8 groups of 240 male subjects repetitively over a 40-minute period. The tests were designed to record visual threshold following prior exposure to photopic conditions (1600 millilambert light source for 3 minutes). Eight groups of 30 subjects each were tested. The range of variation over the 40-minute test period is related to age (Table 2). While the range of threshold values is initially low, it rises as dark adaptation to lower luminance levels proceeds. The increased range of variability after the initial period of dark adaptation and prior to establishment of minimal threshold

TABLE 1

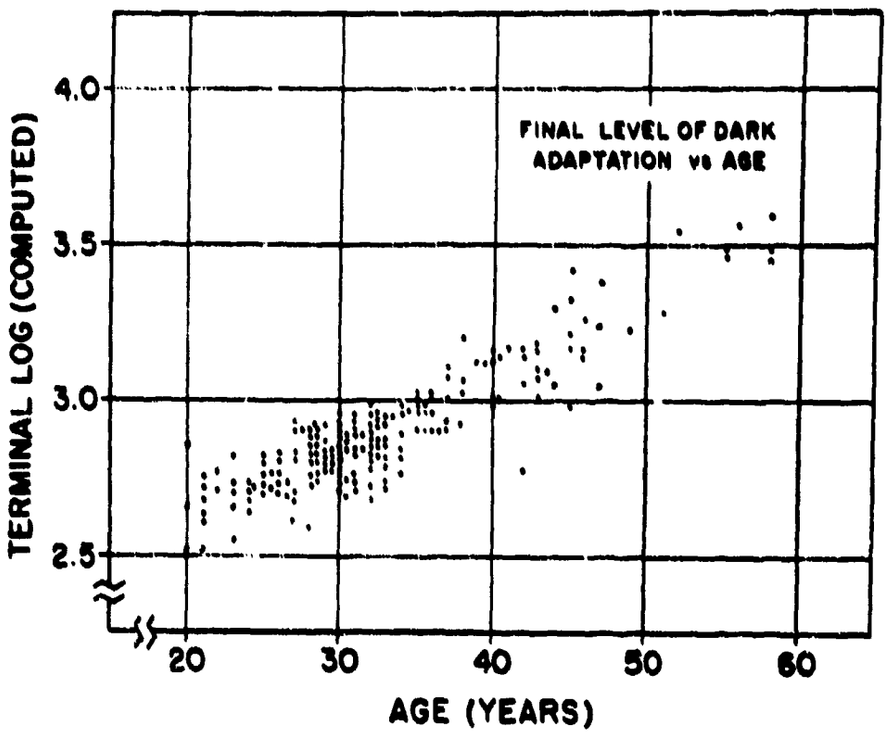
DISTRIBUTION OF NIGHT VISION ACUITY OF BRITISH ARMY TROOPS TESTED FOR TARGET RECOGNITION AT LOW LUMINANCE LEVELS

Age	Number of Subjects	Correct Target Recognition at Luminance Levels (μ millilamberts) of					
		24.0	12.5	8.0	5.2	3.0[1]	0
19	492	213	165	78	26	7	3
20	941	339	339	141	45	13	4
21	933	353	339	147	66	18	10
22	1269	450	448	236	96	24	15
23	1099	359	385	220	94	25	16
24	766	235	282	140	75	18	16
25	664	210	215	146	64	15	14
26	779	232	283	172	73	12	7
27	646	169	238	143	72	18	6
28	588	171	207	128	52	19	11
29	479	127	179	100	56	11	6
%	100	32.4	35.4	19.6	8.7	2.4	1.5

[1] The level of 3.0 μmillilamberts is equivalent to normal scotopic visual threshold after dark adaptation.

(Adapted from Lister and Bishop, 1943.)

FIGURE 9



Scatter diagram showing the relationship between age and final scotopic threshold (terminal log) of dark adaptation. (From McFarland and Fisher, 1955. Reprinted with permission of the authors and the Gerontological Society).

TABLE 2

RANGE OF THRESHOLD EXPRESSED AS PERCENTAGE OF MEAN VALUE FOR MALE SUBJECTS DURING DARK ADAPTATION

Time (Minutes)	Range of Threshold Values[1] (%)		
Age:	16-19	20-29	30-39
2	± 9.9	±14.9	±10.6
4	±13.7	±18.8	±13.7
8	±19.1	±28.6	±19.3
10	±23.0	±31.9	±17.2
19	±23.1	±30.2	±22.9
22	±24.4	±31.6	±19.1
34	±18.8	±31.8	±18.8
40	±13.9	±33.8	±18.8

[1] Range of ±2 standard deviations for inclusion of 95% of the observations for each group of 30 subjects.

(Calculated from data in Domey *et al.*, 1960b, Table 1, p 111).

after 34 minutes reflects the variability of dark adaptation rate. It should be noted that these data are values for 30 men per age group, and it is not possible to discern if the variability increase occurred within the same individual. However, the increased size of the standard deviation for each time period is indicative of variation within individuals over a known time period (40 minutes) (Domey and McFarland, 1961).

Kinney (1963) has reported seasonal variation of night vision sensitivity over a 3-month period of prolonged restriction from sunlight (submerged submarine duty). Age of the 24 subjects was not reported, but the ranges of variability of night vision sensitivity at each test over the 3-month period were similar. Burg (1967a) reported a highly significant change in glarimeter threshold for 21 subjects ages 16 - 24, but no change in glare recovery time for these subjects, nor any significant changes in 249 other subjects age 25 to over 80 years who were retested in a 3-year period.

Another aspect of the relationship between night vision and age is recovery from glare and flash blindness. Burg (1967b, 1968b) reported on glare recovery times for approximately 17,500 Californians of both sexes, ranging in age from 16 to 92. The test measured time to recover threshold when objects were viewed under mesopic conditions. Threshold value for each individual was determined and following intense glare, the time to reestablish visual recognition at the predetermined threshold was measured (Figure 2). As expected, glare recovery time increases with age. However, the range of values for males 16 - 49 is essentially similar. The extent of the time variation for glare recovery to original threshold is large. For example, mean glare recovery time for 1352 males 20 - 24 years of age was 3.92 seconds, one standard deviation (67% of the population) was 3.35 seconds. Thus, 95% of the 1352 men in this age group recovered some lower level of dark adaptation within the mesopic-scotopic range in 0 - 10.62 seconds, or a variation of 270%. It is not surprising to find that the extent of variation is larger in men over 50 years old. Similar observations have been made with other parameters of night vision such as final threshold, rate of dark adaptation, and visual acuity.

Glare recovery time and subsequent form recognition ability under low levels of illumination is a practical measure of visual performance (Burg, 1967a; Wolf, 1960, 1961). Threshold measurement does provide a more critical parameter of physiolog-

ical function of the eye, but the glare recovery task is more analogous to the actual requirements of visual performance under low illumination. These tasks have predictive value in that they measure indirectly the rate of light and dark adaptation in the mesopic-scotopic levels of vision. While age is positively correlated with dark adaptation threshold level increase, sex *per se* does not appear to be a consistent factor. The observations made by Burg in these studies indicate that no consistent difference between males and females is evident in regard to either threshold illumination or glare recovery ability. For both males and females threshold illumination is slightly more related to age than glare recovery. Again, for both males and females, threshold performance is not highly correlated with glare recovery.

Beard (1969) studied sensory perception in a group of 270 men and women, 100 years of age and over. Subjective rating of sight revealed no major difference between men and women. However, it is interesting to note that the study contained 155 females and 115 males. Dalderup and Friedrichs (1969) studied 136 elderly residents of two homes for the aged, utilizing the Stilling color sensitivity test. They observed no sex differences, although the data did indicate that color sensitivity decreases with age, and the loss of color sensitivity appears to occur at slightly incongruent rates in the left and the right eye of both male and female subjects.

4. Variation in Biochemistry of Vision

a. Vitamin A Metabolism

A brief summary of transport, storage, and ocular metabolism of vitamin A suggests a number of factors that could be involved in the wide range of individual differences observed in the normal population. The most evident manifestation of vitamin A deficiency is night blindness.

Although vitamin A is recognized as an essential component of the human diet, minimal and optimal daily requirements of the individual are not known precisely. This imprecision is a reflection of a wide range of dietary intake, dietary content of retinol and carotenoids, absorption, and previously stored supplies of the vitamin. In general, preformed retinol is absorbed directly

through the intestinal wall; retinyl esters are absorbed as retinol, and carotenoids are converted to retinol prior to absorption.

The concepts of retinol absorption, transport, and storage have been reviewed (Fisher *et al.*, 1969; Olson, 1967; Pearson, 1967; Wolf, 1969). Retinyl ester transport and storage includes movement of retinyl esters in chylomicrons through the lymphatic system, via the thoracic duct to the blood stream, and finally to the liver where storage occurs. Liver reserves of retinyl esters are hydrolyzed and the retinol is carried to various body tissues. It has been established that the major portion of vitamin A activity in the blood is transported as retinol bound to a specific protein. The retinol-binding protein circulates in the plasma bound to a prealbumin protein that is identical to the "thyroxine-binding" prealbumin of human plasma (Kanai *et al.*, 1968).

The retina and related ocular tissues receive a rich supply of blood from the internal carotid through the ophthalmic arteries. The total quantity of vitamin A within the eye is quite limited and presumably the retinol-binding protein-prealbumin complex delivers retinol to the sclera, choroid, and retina. Following release and transport to the basal portion of photoreceptive cells, retinol is hydrolyzed and isomerized to the moiety active in the visual pigments. The retinol content of the pigment epithelium decreases in dark adaptation while a concomitant increase of retinal occurs in the retina. In the light adapted state, less total vitamin A activity is present in the retina (Dowling, 1967).

Retinal reduction in the visual cycle is dependent on glucose metabolism primarily by way of the pentose cycle. In the light adapted eye, the presence of *trans*-retinal results in reoxidation of nicotinamide adenine dinucleotide phosphate (NADPH). Thus, pentose cycle activity and ultimately the requirement for both oxygen and glucose are stimulated. Because glycogen storage in the human eye is limited, ocular tissues are almost entirely dependent on an uninterrupted supply of blood glucose (Andrews and Futterman, 1964; Futterman, 1963; Futterman and Andrews, 1964).

b. Vitamin A Nutrition

The dietary content of retinol and carotenoids is affected by geographical, cultural, seasonal, ethnic, and personal

factors (Davis *et al.*, 1969; Pearson, 1967; Wolf, 1969). The plasma levels are highly variable, even in the same individual, as the daily dietary intake affects the retinol content of the blood (Pearson, 1967). Age and sex differences also occur. In general, males have higher serum levels than females and younger children lower levels than adults (Pearson, 1967).

Recent studies suggest that approximately 30% of the North American population have inadequate blood retinol levels (Davis *et al.*, 1969), or liver stores that are below the values considered acceptable by various proposed guidelines (see Table 3) (Hoppner *et al.*, 1968; Interdep. Comm. Nutr. Nat. Defense, 1963; Underwood *et al.*, 1970). It should be noted that normal values have a wide range, and various authors report different values for the normal range (see Table 4).

Recently observed differences in a representative sample of adults in the United States suggest that ethnic background and socioeconomic status may be predisposing factors affecting the levels of vitamin A consumption (Davis *et al.*, 1969; Underwood *et al.*, 1970). Indigenous populations in other parts of the world may have greater vitamin A deficiency states (Blankhart, 1967; Chopra and Kevany, 1970).

Experimental induction of night blindness in man requires rigorous efforts to exclude dietary sources of vitamin A and prolonged time periods to deplete stored retinol (Hume and Krebs, 1949). However, loss of night vision capability from inadequate vitamin A intake is preceded by decreased dark adaptation. Indeed, elevation of the final scotopic threshold is diagnostically useful in assessing vitamin A deficiency.

c. Vitamin A Transport

Retinol circulates in the blood plasma bound to a specific protein, retinol-binding protein (RBP) (Kanai *et al.*, 1968). The RBP complex is bound to a plasma prealbumin (PA). Evidence suggests that one molecule of retinol is bound in one molecule of the RBP-PA complex (Kanai *et al.*, 1968. Smith *et al.* (1970), in developing a radioimmunoassay for RBP, studied

TABLE 3

Interdepartmental Committee on Nutrition for National Defense

SUGGESTED GUIDE TO INTERPRETATION OF BLOOD DATA[1]

Class	Vitamin A (μg/100 ml)	Carotene (μg/100 ml)
High	> 50	> 100
Acceptable	20 - 49	40 - 99
Low	10 - 19	20 - 39
Deficient	< 10	< 20

[1] (From ICNND, 1963).

TABLE 4

NORMAL RANGE OF BLOOD VITAMIN A LEVELS

Reference	Vitamin A (μg/100 ml)	Carotene (μg/100 ml)
Conn, In: Cecil-Loeb (1967)	10 - 30	60 - 180
Altman and Dittmer (1961)	18 - 21	12 - 180
Oser, Hawk's Physiol. Chem. (1965)	10 - 60	40 - 540
Wohl and Goodhart (1968)	25 - 90	80 - 300

the circulating levels of RHP in populations of normal and diseased males and females. The plasma values for males (47.2 ± 1.6 μg/ml) and females (41.0 ± 1.6 μg/ml) were significantly lower in patients with viral hepatitis (14.0 ± 0.3 μg/ml). The narrow range of the standard error of the mean in the 76 normal subjects implies circulating RHP levels are not subject to wide variation. Mean values of RHP saturation by retinol were 88% in males and 82% in females. In both cases the standard deviation was ± 20%. These calculations indicate that while RHP level appears to be relatively consistent, the rate of retinol saturation of RHP is a second source of individual variation in both males and females.

d. Ocular Retinol Metabolism

Moore (1964) concluded that less than 0.01% of the retinol in the average adult is present in the ocular tissues. After release from RBP-PA, retinol is present primarily as the bound form in the visual pigments of the rod and cone cells (Dowling, 1960).

Rushton (1968) has shown that rod and cone cells compete for available retinal. Presumably, under photopic conditions, pigment regeneration in cone cells would be favored, while regeneration in rod cells would dominate in the dark adapted eye. This rod/cone rivalry may be significant in mesopic vision of individuals in situations where body storage and RBP-PA transported retinol levels are highly individualistically variable. Adverse effects on mesopic visual capabilities would be critical in deficient individuals. This problem has not been investigated sufficiently.

The conversion of retinol isomers to retinal prior to binding with opsin to form rhodopsin, and the reconversion of released *trans*-retinal following light absorption by rhodopsin are mediated by reduction and oxidation of nicotinamide adenine dinucleotide (NADP), respectively (Andrews and Futterman, 1964; Futterman, 1963). The glycolytic pathway and the hexose monophosphate shunt contribute to generation of NADPH. Thus, light activation of rhodopsin ultimately stimulates glycolysis and the pentose cycle in ocular tissues. Because glycogen storage in the tissues of the human eye is limited, ocular metabolism is almost entirely dependent on the supply of blood glucose, and availability of this energy depends upon hexokinase phosphorylation by adenosine

triphosphate (ATP). Indeed, ATP plays a central role in oxidative phosphorylation and energy release in ocular metabolism.

Brewer (1969) has recently reviewed the normal range and variations in erythrocyte ATP concentrations in American Caucasians and Negroes. He concluded that there is considerable variation in ATP levels among the individuals in these two populations. In addition, the ATP level of a healthy individual appears constant with time. These conclusions suggested that the ATP level of an individual is to a great extent genetically determined and only slightly modified by environmental influences. The genetic control is multifactorial (Brewer, 1969).

The recent data on mean values for erythrocyte ATP levels have been summarized by Brewer (1969). He concluded that the variation was in part due to analysis techniques, but involved other sources of individual variability. These would include the effect of individual age, the mean erythrocyte age, and the ethnic or population origin of the individual. No sex differences were detected in either the Caucasian or Negro populations (Brewer, 1967).

The relation of these observations on ATP blood levels to ocular metabolism of retinol are speculative. The inter-individual variation and intra-individual consistency suggest a rational basis for additional study. It is interesting to note that several investigators have recently reported lower mean ATP levels in Negroes (Brewer, 1969); yet in 1944, Sheard had suggested Negroes have superior night vision capability but he did not indicate a basis for this difference.

It has been established that 2, 3-diphosphoglycerate (DPG) is an important factor in the binding of oxygen to hemoglobin in the erythrocyte (Eaton *et al.*, 1969). The DPG level varies widely among individuals and there is a significant negative correlation between erythrocyte DPG level and whole blood hemoglobin level (Eaton and Brewer, 1968). While the basis of this correlation is not fully elucidated, the variations in red blood cell DPG that occur in several disease states produce changes in hemoglobin oxygen binding affinity. Furthermore, an increased level of DPG within the individual and among individuals in a population is evident in humans adapted to higher altitudes (Eaton *et al.*, 1969).

The effects of altitude on dark adaptation and night vision are well documented (Brewer, 1970; McFarland, 1952, 1953a, 1960; McFarland *et al.*, 1939, 1945). (For discussion see p 91.)

Based on studies of ATP and DPG blood levels, Eaton *et al.* (1970) concluded that variations in erythrocyte metabolism are critical to maintenance of respiratory homeostasis. The potentiality for alteration of DPG levels constitutes close regulation of the respiratory system with level of oxygen use. The inherent genetic capacity of an individual that determines his "normal" level of DPG and ATP is fundamental to his capacity to adapt to hypoxic stress and maintain adequate oxygen supply to various body tissues, such as the retina.

e. Rhodopsin

Investigations on variability in rhodopsin levels are scant. It is generally held that the inability of night-blind persons to see at low ambient light levels is a consequence of inadequate visual pigment within the photoreceptive cells. Nutritional night blindness implies elevation of the threshold because of insufficient regeneration of the visual pigment, rhodopsin. Congenital night blindness also results in elevated thresholds and alteration of rhodopsin regeneration (Jayle *et al.*, 1959). Several previous studies and, more recently, Carr *et al.* (1966) noted electroretinogram alterations but no evidence of abnormal rhodopsin regeneration in both the dominant and the recessive form of congenital night blindness. In the absence of human data on rhodopsin variations, it is logical to conclude that the variation in final threshold of normal dark adapted individuals may be of neurological origin alone. However, such a conclusion may be misleading (Childs, 1970). The rhodopsins of several vertebrate species exhibit slightly differing absorption maxima (Best and Taylor, 1966). These differences are due to the species specific nature of the protein component (opsin) of the rod visual pigment. There is no evidence that protein configuration in human rod rhodopsin differs with race, sex, or individual.

In this connection, recent investigations in identity and regeneration of visual pigments in fish are of interest. Bridges (1964) has reported that the dark adapted eye of *Notemigonus* (shiner) possesses two visual pigments, one with 11-*cis*-retinal,

and the second with 11-*cis*-hydroretinal. The proportions of the two pigments varied as much as 44% from specimen to specimen in simultaneous collections from the same body of water. No significant differences between the two eyes of the same specimen were noted. In a subsequent study, Bridges (1965) observed that the proportions of the two visual pigments in both *Belonesox* and *Heterandria* sp. varied with the season in which specimens were collected. In both species, more of the 11-*cis*-hydroretinal type pigment was present in the winter with less present in the summer. Individual and seasonal variation in proportions of the two visual pigments were evident in specimen collections from two locations. Variation in the two pigments among individual fish of four different species were observed. While there are no data to suggest more than one type of rhodopsin in human rod receptor cells, these studies suggest inter- and intra-individual differences in visual pigments of both rod and cone cells are possible. Bridges (1964, 1965) suggested that individual differences in fish visual pigments have adaptive value in schooling behavior. The significance of possible seasonal and individual differences in human photoreceptive pigments is unknown.

Synthesis and disintegration of the protein discs that bind rhodopsin is another process subject to variability that could affect night vision capability. The rate of synthesis, movement from the inner to outer segment of the photoreceptor cell, and destruction in the pigment epithelium is known in several vertebrates (Hall *et al.*, 1968; Young, 1970). Data on individual animals does not appear in the published reports and would be of interest, if available.

5. Disease

Jayle *et al.* (1959) compiled an exhaustive review of the effects of various pathological conditions on dark adaptation and night vision. McLaren (1963) reviewed the influence of nutritional disorders on the eye. Vitamin A deficiency, by itself, and in concert with various pathological states that might induce the deficiency is the most common cause of subnormal night vision capability and night blindness. The variation in blood, liver, and ocular levels of vitamin A has been discussed (p 68). Jayle *et al.* (1959) demonstrate the relationship of blood vitamin A levels and scotopic visual ability by reproducing data reported by Glees (Jayle

et al., p 187, 1959). Numerous investigators have shown that scotopic visual thresholds rise with both natural and experimentally produced vitamin A deficiency. However, in many of these studies (Hoppner *et al.*, 1968; Hume and Krebs, 1949) the individual variability in initial vitamin A levels and the length of time between reduction of blood levels and onset of decreased scotopic capability is enormous. A critical study of this variation would be difficult as well as experimentally complex because of the intricacies of vitamin A metabolism in the various body systems.

Certain pathological conditions, other than vitamin A deficiency *per se*, or clinically recognizable ophthalmologic diseases might affect dark adaptation and night vision. For example, gastrointestinal disorders (Adams *et al.*, 1960; McLaren, 1963), tuberculosis (Jayle *et al.*, 1959), hepatitis (Smith *et al.*, 1970), and malaria (Jayle *et al.*, 1959) are reported to adversely affect absorption, transport, and storage of vitamin A as well as alter dark adaptation. The range of individual response over time or within a population when stressed by infectious disease is essentially unknown. In a military population, debilitating disease would require treatment and removal from active duty, and any effect of acute or short-term disease on night vision would very likely be of no operational significance. However, prolonged gastrointestinal or upper respiratory tract infections may not be cause for removal from duty but could affect night vision adversely. In general, the long-term effects of various diseases and their treatments on dark adaptation and night vision are unknown.

The effects of genetic deficiencies and hereditary disorders are better known (Jayle *et al.*, 1959). Presumably, color blindness and more serious disorders such as congenital night blindness, retinitis pigmentosa, Oguchi's disease, albinism, and other functional anomalies would exclude an individual from the military population. However, individual variation might be more evident in persons with hereditary visual disorders. Chapanis (1946), in a study of dark adaptation in color-blind individuals, measured dark adaptation thresholds of three protanopes and four trichromats. He observed a variation of approximately 0.6 - 0.8 log $\mu\mu$L threshold intensity with these seven subjects. This variation is similar to that observed with normal subjects. Berson and Goldstein (1970) have reported that eight subjects with dominantly inherited retinitis pigmentosa have more rapid ERP recovery rates during dark adaptation than normal subjects. Relative ERP amplitudes of the

eight subjects show a 10 - 40% range of variation over the 4-minute test period. While the number of subjects in this study is small, the data suggest individual variability is a critical component of visual characteristics of persons with congenital disorders.

Visual light thresholds have been studied in neuropsychiatric patients as an objective measure of the perceptual distortions that these individuals experience (Rubin and Stein, 1960; Wolin *et al.*, 1965). This field has been reviewed by Granger (1957). Only a few studies report significant differences in thresholds between psychotic patients and normal controls. Pupillary responses, which vary significantly from normal values in these individuals, have been considered a diagnostic criterion.

6. Biological Rhythms

Some individual differences are expressions of fluctuating physiological phenomena. The inherent fluctuation of several components of the visual process have been related to rhythmic periodicity phenomena (De Venecia and Davis, 1963; Ronchi and Ercoles, 1967). This so-called "biological clock" is now a well accepted concept that explains the endogenous rhythm characteristic of numerous physiological processes (Bunning, 1960; Harker, 1964; Mills, 1966). Ronchi and Ercoles (1967) have reported visual system fluctuations that are controlled by both endogenous and exogenous mechanisms (Table 5). The significance of these rhythmic fluctuations in visual functions is unclear.

In addition, light perception by the visual system may function as the receptor for other unrelated physiologic processes. For example, the diurnal cycle of renal excretion appears to be dependent on visual perception of night and day (Lobban and Tredre, 1967). There has been insufficient study to adequately establish the importance of individual variability in both the periodicity of the visual system and those fluctuations induced by the visual system.

7. Pharmacology

All individuals do not respond to therapeutic drugs in a similar manner. The physician recognizes unusual susceptibility or tolerance to drug dosage, and his clinical judgement includes

TABLE 5

RHYTHMIC FLUCTUATION PHENOMENA IN VISION

Period	Frequency	Activity
0.017 - 2.0 sec	0.5 - 60 Hz	Spontaneous cerebral activity
0.1 sec	10 Hz	Alpha rhythm
0.8 - 8.3 sec	0.12 - 1.2 Hz	Pupil size fluctuation frequency
0.4 - 5.0 sec	0.2 - 2.5 Hz	Accommodation fluctuation frequency
0.01 - 0.1 sec	10 - 100 Hz	Eyeball position fluctuation frequency
< 10 sec		ERG responses, threshold sensitivity
2 - 16 sec	3.6 - 30 rpm	Fluctuation of ambiguous figures
2.4 - 12 sec	5 - 25 rpm	Fluctuation of resolution phenomena
5 - 7 sec	8.6 - 12 rpm	Fluctuation of after-image retention
	3 - 13 rpm	Fluctuation of brightness sensation
2 min		Cyclic fluctuation of threshold
4 min		
48 hrs		
a.m. vs. p.m.		ERG and threshold fluctuations
48 - 96 hrs		ERG cyclic fluctuations
2 weeks		Resolving power
several months		Seasonal variation in threshold

(Adapted from Ronchi and Ercoles, 1967).

these factors in selecting the dose of a drug for a specific patient. However, some drugs produce unexpected and undesirable effects, including effects on vision and night vision. The genetics of abnormal drug responses reflecting biochemical variability of individuals has given rise to the new subject of pharmacogenetics (Kalow, 1962; Krantz and Carr, 1969; Motulsky, 1965; Simpson and Kalow, 1966). Individual metabolic differences usually account for toxic drug effects, but they may also explain the therapeutic effectiveness of some drugs (Price-Evans, 1965).

Undesirable effects on mesopic vision including cycloplegia, increased intraocular tension, amblyopia, and interactions with the visual pigments, or corneal deposits can be caused by some drugs. These untoward drug reactions are dose related; however, there are wide individual differences in the sensitivity of subjects. Toxic reactions of this character usually are unexpected and not detected in their incipient stages. The effects of drugs on vision have been reviewed (Arden, 1966).

Relatively few drugs have been studied for their effects on dark adaptation or night vision, and there are few reports of adverse effects on dark adaptation resulting from administration of therapeutic agents (Fisher *et al.*, p 109, 1969). In general, any drug that impairs oxygen transport or utilization could be expected to affect adversely visual sensitivity.

Ephedrine is used as a mydriatic by instillation of a solution into the eye. Chen and Poth (1929) found that ephedrine mydriasis, as produced in Caucasians, could not be produced in the Ethiopian. The degree of pupillary dilation in the Mongolian was intermediate between these two extremes. Angenent and Koelle (1953) reported ephedrine is less effective in those individuals who have heavily pigmented irides than in those in whom the iris is light-colored. They attribute this difference to a greater content of dopa oxidase and possibly other enzymes in heavily pigmented irides. These enzymes may inactivate the alkaloid in the eye of these subjects and thus prevent mydriasis. It is possible that the observations of Walls (1944) and Jayle *et al.* (1959) on the relations between eye pigmentation and night vision might be explained on an enzymatic basis.

The action of drugs on retinal tissues can be studied in animals using electrophysiological techniques, especially the

electroretinogram (ERG) (Arden and Fojas, 1962). These studies can assist in understanding the toxic visual reactions of such drugs as the phenothiazines and the antimalarials in man. The electro-oculogram (EOG) has been employed with some success to elucidate the mechanism of action of chloroquine in causing retinopathies in patients (Arden, 1966). In chloroquine retinopathy, the EOG is abnormal, there is an associated field loss, dark adaptation is incomplete, and the ERG is abnormal (Arden, 1966). Why some individuals are more susceptible to chloroquine retinopathies is not understood. These variations in drug susceptibility to chloroquine pose a serious problem for the physician and prediction of untoward reactions may be predicated, in part, on the subject's EOG (Arden *et al.*, 1962).

Other drugs, including the effects of alcohol and barbiturates, may be studied for their actions on the visual receptors by use of the EOG. Thus the decrease in the dark adapted threshold observed in man after alcohol ingestion may be demonstrated by an analysis of the potentials recorded in the EOG.

The ocular toxicity of drugs such as the phenothiazines (Fisher *et al.*, 1969; Potts, 1964) and the antimalarials (Bernstein *et al.*, 1963; Carr *et al.*, 1969) appears to be related to the selective binding and storage in the pigment of the uveal tract. The dynamics of the ocular toxicity of chemical compounds of this character are not understood, but wide individual differences are recognized. The effects of one phenothiazine drug in producing impairment of dark adaptation apparently was related to blocking visual purple synthesis (Burian and Fletcher, 1958). Antimalarial drugs (quinine, quinacrine, chloroquine) in usual therapeutic doses do not produce adverse effects on dark adaptation (Carr *et al.*, 1969; Harvey, p 39, 1970).

Less specific drug effects related to altered visual functioning with attendant behavioral changes have been reported. Impaired dark adaptation (Apt, 1960), damage to retinal elements (Weekley *et al.*, 1960), toxic amblyopia, decreased ability to discriminate colors, blurred vision, and impaired depth perception (Jones, 1961; Lear *et al.*, 1962; Palmer, 1963), and disturbance of color vision (Cox, 1961) have been recorded. Some tranquilizers have produced acute myopia (Yasuna, 1962), altered depth perception, poor accommodation, and blurred vision (Fleminger and Groden, 1962; Friedman *et al.*, 1961; Höhn *et al.*, 1961; Lambert

et al., 1962; Murray, 1961; Pollack, 1962).

Certain psychotropic drugs will produce adverse changes in visual functions and visual perception including dark adaptation (Apt, 1960), depth perception (Costello, 1960), brightness perception (Weiner and Ross, 1962), visual discrimination (Fuster, 1959), and visual threshold (Carlson, 1958; Krill *et al.*, 1959). No drugs or chemical substances have been found that reduce the absolute visual threshold of healthy adults (Harvey, p 42, 1970). Drug effects may antagonize some adverse physiological change or environmental factor but, despite contrary reports, valid evidence for enhancement of night vision by drugs is not available.

Some drugs reportedly enhance performance requiring visual motor tasks. Amphetamine has been studied extensively in this respect (Hauty and Payne, 1958; Kornetsky *et al.*, 1959; Mackworth, 1950; Payne and Hauty, 1955). It is impossible to differentiate the visual effects of amphetamine from the effects on skeletal muscle reflex responses. The latter are most likely the more prominent actions responsible for enhanced performance.

Wide individual variations may be related to inherited endogenous factors associated with differences in enzymes, functional proteins, or structural proteins. These personal characteristics are as unique as physical features and anatomic differences and explain some drug effect on the eye. In the eye, inherited anatomic features with a narrow angle at the interior chamber of the eye will cause an obstruction of flow of aqueous humor into the canal of Schlemm. This inherited trait may cause glaucoma, especially after instillation of mydriatic drugs. Inherited differences in the structure of the trabecular network of the eye may also cause glaucoma after the application of corticosteroids (Armaly, 1968).

Unfortunately, these studies do not document a range of ocular drug toxicity over a wide dosage range in a number of ostensibly normal subjects. Recently, individual drug metabolic differences have been studied and data on metabolic patterns reported. It is recognized that these individualistic features of the fate of a drug in the body must be assessed to obtain the optimal therapeutic response. This is difficult at present because analytical methods are just beginning to be developed for human drug distribution studies (Cash and Quinn, 1970). Because the visual process in man can be measured easily this may be an excellent test feature

to detect drug metabolic differences. Future studies on the individual characteristics of mesopic and scotopic vision should include drug metabolic effects.

Insulin hypoglycemia causes changes in the foveal intensity discrimination thresholds (McFarland *et al.*, 1943). A decrease in visual sensitivity (a rise in visual threshold) was noted when the blood sugar level fell below 65 - 70 mg/100 ml. There was little variation among the four subjects in the experiment, and the changes were related to an impairment of the oxidative processes in the central nervous system. The primary photochemical reactions were not believed to be the site of hypoglycemic effects because these mechanisms presumably are not altered *in vitro* by anoxia. Apparently, the mechanism of hypoglycemia causing a rise in visual threshold is oxygen deprivation of the brain cells, because inhalation of oxygen causes a reversal of the impairment. These findings support earlier work on the effects of glucose (hyperglycemia) in diminishing the visual impairment caused by hypoxia (simulated altitudes of 12,700 to 17,200 feet) (McFarland *et al.*, 1945). Three subjects were studied. In one, oral glucose consumption caused a diminished visual impairment from a simulated altitude of 13,800 feet to an altitude equivalent to 8,000 feet – a 42% reduction. In the other two subjects the lowering of the "physiological altitude" was 25 and 48%, respectively. These tests were made by measuring the differential intensity thresholds for vision at low brightness levels. This is said to be a sensitive and objective index of visual impairment caused by anoxia.

Drugs that cause hypoxia of the central nervous system, regional blood flow restriction in the brain, or changes in the oxidative processes of brain cells, may produce measurable effects on vision or dark adaptation. These actions may be primary or secondary drug effects, e.g., vascular constriction or metabolic poisons. The drug effects may interact with metabolic, biochemical constituents that could be individualistic, or they may be influenced by environmental factors. From a military standpoint, drug therapy, environmental extremes, and individual differences are factors for consideration in future studies on the performance abilities of the individual soldier related to dark adaptation and night vision.

C. BEHAVIORAL ASPECTS

1. Motivation and Experience

Superior night vision capability involves more than the process of dark adaptation and attendant neurophysiological alterations in the eye. The quality of an individual's night vision also reflects his motivation to perform the visual task, his experience, and the extent to which he has learned to utilize the dark adapted eye efficiently.

Empirically, the desire for superior performance appears to result in enhanced night vision. The observation that well motivated subjects perform well is classic. Unfortunately, the concept of drive or motive remains one of the more controversial aspects of behavioral science (Appley, 1970). There is no rapid or direct measure of motivation; it is usually determined by inference derived from observing behavioral changes.

There do not appear to have been any longitudinal studies of the role of motivation in performance of military duties requiring night vision. In earlier programs during World War II, motivation was recognized as a prerequisite to benefits from night vision training.

The confidence an individual has in his own night vision capacity is a reflection of his experience or required dependence on that aspect of his visual system. The more an individual has had to rely on night vision, the more he has learned empirically to use his dark adapted eyes efficiently. No studies, other than anecdotal material, on individual variations have been uncovered. However, it is obvious that experience and learning were the bases of training programs that have been used intermittently for many years.

2. Night Vision Training

Night vision training involves learning the proper use of the parafoveal retina, slow systematic fixed-point scanning of the area of inspection, and recognition of the importance of protecting and maintaining dark adaptation. During World War II elaborate

night vision training programs were organized to teach large numbers of soldiers, sailors, and airmen the basic elements of night vision enhancement for scouting and patrol duties to detect and recognize objects at night. These programs have been reviewed by Harvey (1970). Unfortunately, there was no critical assessment of the value of these training programs, and no documented reports present evidence of substantial improvement of night performance as a result of this training.

A description of various types of night activities that require mesopic vision includes consideration of natural phenomena (moonlight, cloud cover, and terrain) and artificial factors (glare, colored lights, cigarette smoking). The maintenance and enhancement of night vision by training is known to embrace a majority of these natural and artificial factors and the physiological aspects of a specific individual (Jayle et al., pp 301-361, 1959). In recent years, the emphasis has been on civilian highway night vision problems and aircraft landing and takeoff at airports at night. In spite of the obvious need for more information about individual driver or pilot performance under night operations, there are few reports. Essentially, the military and civilian requirements are the same in these areas and their common needs should be met by a unified research program. Individualistic features of night vision and dark adaptation, training, and real-life field situations should be studied to develop criteria for performance. Licencing in civilian communities for highway driving or pilot testing for aircraft operations should include accurate assessment of the individual's night vision and dark adaptation threshold.

There are many practical aspects of night vision training that have been developed in past years. These techniques include the wide experience of training centers for military personnel evolved by the Johnson Foundation, University of Pennsylvania; the Royal Canadian Air Force Biophysics Laboratory, McGill University, Montreal; the U.S. Army Fort Knox Armored School; the U.S. Army Behavior and Systems Research Laboratory, Arlington, Virginia; the U.S. Submarine Base, New London, Connecticut; and the British Central Night Vision Training School, Upper Heyford, England. Their work with various tests and training devices has been reviewed by Harvey (1970). Future Army night vision training programs that include specialized skills for specific key individuals should embrace the experience gained in

these historically significant programs. Training of this character is also important in civilian activities, especially for workers in the fields of ground transportation and aviation.

The details of night vision training were reviewed in 1951 by the National Research Council Committee on Vision (Clark, 1951; Verplanck, 1951). Emphasis is placed on demonstrating to the candidate trainee the importance of the factors of: a) dark adaptation and the preservation of dark adaptation; b) off-center vision; c) loss of visual acuity; d) loss of contrast acuity and color vision; e) methods of scanning; f) glare, and g) ease of fatigue of a retinal area.

As noted previously, there are few reports that attempt to validate the benefits of night vision training. Vos *et al.* (1956) noted the reports of the Armed Forces Committee on Vision concerning enhancement of night vision by training but concluded that the effects of training were negligible. Barlow (1956) implied that an individual can consciously reduce his absolute threshold by 0.1 log unit, although Hallett (1969a) suggested subsequently that this intra-individual variation was not causally related to conscious effort or "learning." On the other hand, Pirenne *et al.* (1957) did show increases in perceptual efficiency after training. Subjects with initially lower thresholds decreased their thresholds as did subjects with initially higher thresholds; in general, the rank order of increased perceptual efficiencies were correlated with initial rank order of threshold values. It must be noted that Pirenne *et al.* (1957) used 22 subjects, 18 women and 4 men, all of whom (with one exception) were highly motivated and intelligent university students. In general, other investigators agreed that training is useful; however, the value of various types of training protocols has not been validated extensively. The relative effectiveness of night vision training and the concomitant use of night vision devices for Army field operations is currently being studied (Hyman and Sternberg, 1969; Sternberg and Banks, 1970).

3. Perception and Performance

Perception involves recognition of the visual stimulus and performance, the cognitive and behavioral response to recognition. In this sense, night vision and subsequent activity are conditions under which certain behavioral patterns emerge.

Individual differences are evident, but adequate measurement techniques are lacking.

Rather than examine the extent of individuality, a more rational approach of task definition and assessment of permance relative to an expected norm would seem appropriate (Hinrichs, 1970). Individual variability in tracking ability, target recognition, or other tasks is a useful guideline in selection and assessment procedures or learning situations. Numerous recent studies (Jayle *et al.*, 1959; Kinney, 1968; Kolers, 1968; Stern, 1970; Sternberg and Banks, 1970; Vicino, 1970) have used these techniques to provide a basis of selection or assessment. Obviously, the behavioral activity in actual test situations involves more than dark adaptation of the retina. In this context, performance of tasks using the dark adapted eye is a complex behavioral phenomenon.

4. Stress

An individual is constantly exposed to a multiplicity of sensory stimuli; however, only a fraction of these are consciously perceived. In life-threatening situations, man may be "stressed" by these stimuli. In this sense, stress involves selective alteration of physiologic processes and behavior as a reaction or adaptation. Situations that induce stress include: a) natural hazards of the environment; b) conditions of uncertainty producing anxiety; c) sensory and perceptual saturation or overloading; and d) sustained maximal energy output.

Stress is associated with certain basic changes in nervous and endocrine system function. Recognition of threatening situations results in elevated adrenocortical hormone production and the relative increase in blood and urinary hormone levels are, in general, directly related to the stress experienced by the individual. There are wide individual differences, both in the range within which adrenocortical hormone levels normally fluctuate and in the extent to which they are elevated in stress. The consistent pattern of individual differences at this fundamental level suggests individual variations in overt response to multiple stressors.

In a review of the effects of stress on visual functions, the critical need for improvement in clinical measurement of various

parameters of the visual system under stress were noted. In addition, although stress suggests the general occurrence of regressive changes in the visual system, it may enhance certain functions of visual performance (Rose, 1968).

In the same symposium, J. Brown (1968) reported on his studies of certain patterns of motion, variation in atmospheric gases, drugs, and high light levels as stressors of the visual system. Individual differences were observed in response to whole body vibration, angular rotation, atmospheric contamination with ozone, several drugs, short flashes of intense light, and fatigue. With several of the stressors, reduced levels of response were generally observed, but a few subjects exhibited enhanced visual function. While no extensive documentation of individual variation was included in these studies, the techniques described would be useful in the study of the range of individual differences in night vision to various stressors. It would be of interest to relate changes in dark adaptation and night vision to both the subjective evaluation of stress and the altered levels of adrenocortical hormones.

Leibowitz (1970) has reported recently on the detection of peripheral stimuli under psychological and physiological stress. Various stressors produced a diminution of the ability to process peripherally presented information. These experimental techniques could be used in studying individual differences in alteration of scotopic capability by various physiological and behavioral stressors.

The environmental factors functioning as stressors that may affect individual variability in dark adaptation and night vision are summarized in the next section of this report.

VI. EXTERNAL FACTORS AFFECTING VARIABILITY IN SCOTOPIC VISION

A. SEASONAL VARIATION

Sweeney *et al.* (1960) showed that scotopic visual thresholds in three subjects varied seasonally. The normal variation related to seasonal differences were roughly equivalent to the normal variation in the population, i.e., 1 log unit at threshold. The seasonal variations were correlated with exposure to sunlight; elevated thresholds occurred in the three subjects in mid-summer and lowest thresholds occurred in mid-winter. The seasonal variations did not alter the individual differences; that is, the subject with the lowest threshold exhibited his superiority regardless of season. In a subsequent study, Kinney (1963) found no evidence that further restriction in exposure to sunlight would enhance night vision capability beyond that noted in the study of seasonal variation. These investigations point out the problem of testing night vision of individuals at different times of the year, after different regimens of light exposure, or after rapid movement from one hemisphere to another.

B. GEOGRAPHIC FACTORS

Night blindness and reduced scotopic capability has been observed throughout the tropic and temperate zones (McLaren, 1963). This widespread but endemic incidence suggests that geographic factors may be important. However, where scotopic impairments are present in a population, the most prevalent concomitant factor appears to be the occurrence of malnutrition, especially vitamin A deficiency (McLaren, 1963). McLaren (1968) has noted that in the more economically advanced countries, the elderly have the majority of the visual defects; while in the poorer countries, blindness and visual defects are more evident in children. In general, socioeconomic considerations rather than geographic factors appear to explain differences in visual abilities observed throughout the world (Jayle *et al.*, 1959).

There is reasonably good evidence to suggest that geographical location can indirectly affect dietary intake of vitamin A and, although no analysis of scotopic vision was included, reduced night vision capacity may be implicated. Hoppner *et al.* (1968) have studied the vitamin A storage levels in Canadians. In an extension of these studies to a wider geographic area, the investigators noted a trend to low vitamin A storage levels in the inland urban resident (Murray *et al.*, 1970). Utilizing food consumption figures, the "apparent" vitamin A intake for Canadians in 1964 was estimated at 2040 μg (6800 IU) per person per day. Hoppner *et al.* (1968) concluded that in view of this estimate it must be assumed that nutritional habits and some other unknown environmental factors influence vitamin A storage levels in the liver of normal Canadians. The prevalence of vitamin A and protein deficiencies are known to follow a seasonal pattern (Interdep. Comm. Nutr. Nat. Defense, 1966). In this study, the incidence of vitamin A deficiency was related to seasonal differences in dietary intake of fruits and leafy vegetables. Compromised scotopic ability would probably occur under such conditions only where liver stores of vitamin A were marginal or deficient (Jayle *et al.*, 1959).

Confidence in night vision ability, motivation, and familiarity with the terrain interject a behavioral component into scotopic capability of individuals that is indirectly related to geographic considerations. This problem was summarized by McFarland (1969) in a review of the effects of altitude on visual acuity and light sensitivity.

He concluded:

> "The variation in response from person to person has proved to be an important aspect of study of the effects of high altitude both in the laboratory at sea level and in mountainous areas. Individual variability is of great importance, therefore, and places great emphasis on initial selection of personnel in regard to age, physical fitness and ability to perform, among many other factors.
>
> "The combined effects of altitude with other variables such as (1) drugs or sedatives for sleeping, (2) alcohol, (3) carbon monoxide from cigarette smoking, and (4) diet, are factors which must be considered."

C. ENVIRONMENTAL INFLUENCES

Climatic factors such as rain, fog, and haze reduce visual capability primarily by decreasing visual field and visual contrast. The effects of reduced ambient illumination under such conditions would impair scotopic vision. Characteristics of the terrain such as foliage density, background contrast, and color hues within the terrain might affect night vision. In regions where snow cover or light-colored soils are present, ambient light levels at night would not be as low as situations where reflective surfaces are absent. At increased altitude the decreased oxygen content of the atmosphere does affect visual capability. With the exception of these latter two factors, climate and terrain characteristics have minimal influence on individual night vision ability.

1. Ambient Light Levels

Scotopic visual thresholds are known to rise in summer months when the ambient light levels are highest for each 24-hour daily cycle (Sweeney *et al.*, 1960). However, the matter has not been studied extensively, and individual differences in visual thresholds should be examined in a number of men under standardized conditions. Preexposure to light, the intensity of illumination, light wavelength, and duration of light exposure are factors that influence a subject's subsequent ability to see under reduced illumination. Unfortunately, few reports include these aspects in studies on night vision and dark adaptation in man, and no information could be found on individual differences between men.

In one study, bright sunlight exposure for five hours as contrasted to indoor illumination did not adversely affect subsequent maximum dark adaptation (cited by Harvey, p 36, 1970). However, in a more extensive study with 25 to 30 subjects, Hecht did find adverse and cumulative effects of sunlight exposure on dark adaptation threshold when the subjects were exposed to three to six hours of sunlight daily for 25 days (cited by Harvey, p 36, 1970). Immediately after sunlight exposure (within several hours), the absolute threshold for dark adaptation was elevated. This finding is frequently reported, but no attempt has been made to publish individual figures or deviations from observed mean values.

Rapidly changing light intensity, especially at low levels of illumination, requires rapid adaptation for effective vision. There are fundamental differences between experimental laboratory conditions with fixed levels of illumination and situations important to the soldier that require efficient vision with changing levels of illumination. Until recently, relatively few studies have included the factor of changing light intensity to realistically assess actual field situations. Only sudden bright illumination, or glare, has been studied extensively with respect to its influence on subsequent adaptation to night vision (Fisher *et al.*, 1969). The effects of glare and bright sunlight have been reviewed by McFarland (pp 182-184, 1953) as these influence the airman's ability to see at night.

Sudden or prolonged exposure to high luminance produces a rapid increase in visual threshold and subsequently decreased visual function. This phenomenon of "flash blindness" can induce temporary or permanent loss of vision (Davies and Randolph, 1967). Age is known to be a critical factor in recovery from temporary flash blindness (Wolf, 1967). This progressive decrease in recovery of dark adaptation following exposure is analogous to glare recovery and does vary not only with age but among individuals (see p 29).

2. Oxygen Levels

Restriction of an adequate supply of oxygen to the central nervous system rapidly produces alterations in visual functions. Indeed, visual changes are early and reliable signs of hypoxia and are used to reflect the integrity of functioning of the brain. With adequate test systems of visual function, individual response to oxygen lack can be detected. For this reason, light sensitivity measures have been used as criteria of change following hypoxia in man. These tests include differential brightness sensitivity, i.e., the ability to distinguish differences in brightness or light intensity, visual thresholds, critical flicker fusion threshold, visual field changes, and color sensitivity zones in the visual field (Kobrick, 1970; McFarland, 1952; Smith, 1965; Tune, 1964).

Other aspects of visual performance have been measured during hypoxic states including acuity, accommodation, muscle balance, and refractive changes (Ohlbaum, 1969). The effects of hypoxia on the visual system and vision have been reviewed by Van Liere and Stickney (1963). It is noteworthy that no

mention was made in these reviews of individual differences in the numerous visual tests conducted over the years by many workers.

Carbon dioxide has been studied in low concentrations in the respired air for any effects on vision. Concentrations commonly regarded as innocuous and not associated with hypoxia have been reported to cause slight impairment in night vision and green color sensitivity (Weitzman *et al.*, 1969). Unfortunately, only one subject was used in the experiment and additional reports have not been found.

The hypoxia associated with high-altitude flying has been examined for its effects on dark adaptation. These studies have been reviewed by Harvey (1970). The hypoxia produced by 17,000 foot altitude causes an increased dark adaptation time, slightly reduced field of vision, reduced accommodative power, but no effect on objective convergence. Individual data are not cited in the reports.

Operators of motor vehicles or aircraft are required to perform exacting tasks at low levels of illumination and may suffer from hypoxia — the former from carbon monoxide-induced hypoxia and the latter from altitude hypoxia. A decrement in performance resulting from visual changes may be critical. Unfortunately, the studies reported do not cite data for individual differences and have not included night vision or dark adaptation among the test procedures.

Kobrick (1968) studied the effects of acetazolamide on visual performance in two groups (18 men each) of soldiers taking part in a military field study at sea level and 12,800-foot altitude. Each subject wore red-filter goggles for 30 minutes and then removed the goggles after donning a light-proof hood attached to an orthoptic-type vision tester. Subjects were tested for monocular and binocular near and far visual acuity and binocular stereopsis. The tasks were performed at a dim field luminance (0.1 ft L) and then repeated at conventional test-field luminance of 10.0 ft L with the hood removed. Other visual tests were made and the battery of tests repeated after transporting the men to 12,800 ft.

On the average, no significant decrements were noted in any of the visual measures. However, while no group differences were observed, the author noted that, "... the possibility still

remained that some subjects might have been more severely affected than others by the experimental conditions." Attempts to discover marked differences between the scores for the control group and the drug group revealed as many improvements as decrements in performance. It would be valuable to have the individual scores from studies of this type to investigate the correlations with other factors not related to the specific study. A subsequent study by this author on individuals tested for color sensitivity zones in the visual field under high and low stimulus luminances at simulated altitudes (hypoxia) of 0, 13,000, 15,000, and 17,000 ft did not include individual data (Kobrick, 1970).

Fundamental to an understanding of the effects of hypoxia will be an explanation of the role of the bound phosphorylated compounds DPG and ATP of the red blood cell. These compounds are involved in the oxygen dissociation properties of hemoglobin and are significant in oxygen transport (Grisolia *et al.*, 1970). The relation of DPG and ATP red blood cell levels to altitude hypoxia has recently come under study and may lead to an explanation of observed individual responses to hypoxia.

Brewer and his associates have established that levels of red cell DPG are influenced by altitude, exercise, disease, and genetic factors (Brewer *et al.*, 1970). Hypoxia from any cause, including carbon monoxide, will increase the levels of DPG. Thus in polycythemic persons at altitude, or in chronic smokers (those with some portion of their hemoglobin bound as carboxyhemoglobin), the DPG levels are significantly elevated over altitude-acclimatized individuals or nonsmokers. It would be informative to follow the visual functions of a group of men correlating these sensory changes with hypoxia and the corresponding biochemical variables.

Breathing pure oxygen at or below normal atmospheric pressure does not influence dark adaptation (Eckel, 1951; Herlocker *et al.*, 1964; Sheard, 1945). Kent (1966) reported that breathing oxygen at one atmosphere caused decreased rod and cone sensitivity at threshold illumination in one of five subjects. Anderson (1968) studied the effects of oxygen breathing on dark adaptation in five subjects at higher than normal atmospheric pressure. These men tolerated exposure to arterial oxygen tension estimated at 1,860 mm Hg with no detectable effect on the rate of dark adaptation or final thresholds. These authors concluded that apparently the metabolic and neural processes involved in human dark adaptation are not

significantly affected by exposures to 100% oxygen for 35 minutes, as tested under the conditions of their experiment. There were individual responses to the effects of oxygen (muscle twitching, dizziness), but the dark adaptation curves were within the range of control values. In addition, the visual fields of subjects participating in a similar experiment and breathing 100% oxygen for 20 minutes were not changed.

3. Environmental Chemical Contaminants

Carbon monoxide (CO), cyanide, and ozone cause changes in visual acuity at very low concentrations in the respired air. CO has been studied in greatest detail because it is a common environmental contaminant (Goldsmith and Landaw, 1968). The effects of CO and hypoxia are additive (Halperin *et al.*, 1959; McFarland, 1952; McFarland *et al.*, 1944), and CO may be more harmful for visual performance at high altitudes than at sea level. The visual threshold is raised and night vision may be impaired. Cigarette smoking may accentuate environmental factors because cigarette smoke contains CO (McFarland, 1970). An early study attributed the adverse effect of smoking to nicotine (Sheard, 1946); however, the present evidence strongly suggests that CO is the factor most significant in producing visual effects (McFarland, 1953). Experimental exposure to CO has been conducted to detect effects on time estimation, reaction time (driving simulator), hand steadiness, manual dexterity, and evoked responses in the electroencephalogram (Stewart *et al.*, 1970). Vision sensitivity tests were not employed, but these performance tasks required visual recognition of cues. The authors concluded that there was no significant impairment of "vision" as a result of exposure to concentrations of CO as high as 100 ppm in the respired air.

Cyanide resembles CO in that it binds hemoglobin and forms cyanomethemoglobin. In addition, cytochrome oxidase is inhibited by cyanide and cellular respiration stops. Hence, cyanide produces cytotoxic hypoxia. Trace quantities of ingested or inhaled cyanide can cause a deficit in oxygen transport and in this way have an additive effect to the adverse vision produced by environmental hypoxia.

Ozone in the respired air in concentrations of from 0.05 to 0.20 ppm has been reported to cause a decrease in visual

acuity (Jaffe, 1967). Chemical contaminants by aircraft engines, gunfire, or internal combustion engines should be considered potentially toxic elements that may produce indirect adverse effects on vision.

The combined effects of hypoxia, environmental toxic substances, physical stress, use of alcohol or drugs, and physical or mental fatigue may be greater than presently recognized. These influences on the vision of the soldier should be assessed as they are encountered under military situations. These studies require accurate data on the concentrations of all environmental contaminants, reliable, quantifiable measures of vision of the man, and recognition of the importance of individual variability.

VII. CONCLUSIONS

A. GENERAL CONCLUSIONS

- Review and analysis of this subject suggests that differences among individual men may be substantial enough to influence their performance in sustained and continuous military operations under low levels of ambient luminance. More importantly, analysis of the limited data indicates that, within all age groups, the normal variation among individuals may be large enough to affect adversely the performance of certain military tasks carried out under darkness.

- The influence of individual variation on the efficient use of night vision devices is of particular concern. Recent research by the Behavior and Systems Research Laboratory and the Combat Developments Command Experimentation Command, suggests that individual differences should be considered in developing concepts of improved nocturnal tactical capabilities. (See p 47.)

- The recognition of individual differences as an important factor in ability to see at night indicates the need to consider routine determination of the night vision capability of a man when he is assigned to particular tasks. Accurate determination of night vision capability would be a logical basis for the selection of key individuals for specific tasks and exclusion of others who should not be assigned responsibilities that require critical night vision. (See pp 36 and 47.)

- It is generally assumed that the "average" healthy North American male receives adequate dietary vitamin A and has "acceptable" liver stores of vitamin A. Consequently, it is assumed that his scotopic vision is within the normal range. Recent studies of dietary intake have shown seasonal variation in vitamin A levels and have revealed reduced vitamin A blood levels and liver stores in a significant segment

of the "normal" population. The relation of these findings to the range of scotopic visual capability in ostensibly healthy young men is unknown. There is an urgent need for the Army to establish the extent of individual variation in vitamin A nutrition and to assess its importance in night vision in the soldier. (See p 68.)

- Diseases such as upper respiratory tract infections, viral hepatitis, diarrhea, and gastrointestinal disorders are known to adversely affect vitamin A metabolism. A wide range of inter- and intra-individual variation to various disease states probably exists, but the effects on night vision and performance are essentially unknown. Because reduced vitamin A levels or stores compromise scotopic visual capability, there is a critical need to reassess the effects of chronic debilitating diseases on scotopic vision of soldiers who are required to perform military duties at low levels of ambient illumination. (See p 74.)

- Quantitative data from biochemical and physiological tests, subjective measures from scotopic vision tests, and scores from visual performance tests all show a statistically normal or skewed pattern of frequency distribution. Presentation of data in frequency distribution curves reveals individual variation as a clearly identifiable component of experimental results. To provide adequate recognition of variation, intra- and inter-individual differences should be identified in literature data presentations.

- Relatively few drugs have been studied for their effects on dark adaptation or night vision; however, there are some reports of adverse effects on dark adaptation resulting from administration of therapeutic agents. Individual differences in response to drug therapy are factors for consideration in studies on the performance abilities of the individual soldier. Future studies on the individual characteristics of mesopic and scotopic vision should also include metabolic effects of therapeutic and illicit drugs. (See p 76.)

- Differences in the scotopic visual capability among individuals are well substantiated, but variation within the individual over relatively short time spans is less well documented. The progressive deterioration of visual capabilities with age over several decades is well known, but diurnal, seasonal, and other rhythmic fluctuations in the various biochemical, physiological, and behavioral parameters of night vision have not been investigated extensively. More research investigations are required to establish the significance of individual variability in these periodic fluctuations of vision and those rhythmic somatic responses that depend upon light reception by the visual system. (See p 76.)

- Various factors in the military environment produce mild to severe hypoxia. Because hypoxia is known to affect dark adaptation and night vision, the extent of decrements in performance resulting from visual changes may be critical. With few exceptions, most studies on the effects of hypoxia do not cite data for individual differences and have not included night vision or dark adaptation among the test procedures. There is a critical need to establish the range of scotopic effects of various hypoxic conditions and to develop additional information on inter- and intra-individual variation in response to hypoxic exposures.

B. SUGGESTIONS FOR FUTURE RESEARCH

- The genetic bases of variation in dark adaptation and night vision might be better understood from extended longitudinal studies of related persons, i.e., human familial units that include several generations. These studies might include evaluation of the biochemical aspects of ocular metabolism, e.g., erythrocyte adenosine triphosphate and diphosphoglycerate levels that are known to exhibit inter-individual variation and intra-individual consistency. The relation of these factors to ocular metabolism in the dark adapted eye is essentially unknown. (See p 71.)

- Electrophysiological techniques, such as the electroretinogram could be useful in longitudinal studies of the range of individual variation in the dark adaptive process. Because they provide objective data by measuring evoked electrical potential changes, these techniques would be useful in determining the extent of neural inter- and intra-individual variation during dark adaptation. (See p 24.)

- Relatively little research has been conducted on the effects of environmental contaminants on scotopic vision. Toxic substances such as ozone, the oxides of carbon, nitrogen, and sulfur, and several hydrocarbons are produced by vehicular and aircraft engines and various weapons. There is a need to examine the effects of these environmental contaminants and the range of individual responses to these compounds during dark adaptation and night vision. (See p 90.)

- Bioengineering techniques have been applied to multiphasic screening for early detection of disease. Multiphasic screening includes automated clinical laboratory and psychophysiological tests that segregate members of a population who require further diagnostic evaluation. In the study of individual variability with respect to night vision and dark adaptation in man, reference has been made to numerous

biochemical and physiological variables. If selection for night vision proficiency were one of the basic criteria, it might be profitable to incorporate individual night vision testing into multiphasic screening programs.

- Techniques have been developed that are useful in screening mesopic and scotopic visual capability of a relatively large number of individuals rapidly. The Army Night Seeing Tester, the Naval Medical Research Laboratory test procedure, as well as various dynamic visual acuity and glare recovery tests, (e.g., the photostress test), should be used to establish the extent of individual differences in normal subjects. Such tests would provide not only normative data but also a partial basis for selection of individuals with superior mesopic and scotopic vision. (See p 36.)

VIII. BIBLIOGRAPHY

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IX. GLOSSARY

Adaptometer	A device for determining the course of dark adaptation and for measuring the perceived light threshold.
Amblyopia	Dimness of vision; partial loss of visual acuity or "sight," in the absence of correctable defects or organic lesions in the eye structure and optic nerve.
Ametropia	Imperfection in the refractive powers of the eye, so that images are not brought to a proper focus on the retina, producing hypermetropia, myopia, or astigmatism.
Cycloplegia	Paralysis of the ciliary muscle of the eye; loss of ability to accommodate.
Diopter	The refractive power of a lens with a focal length of 1 meter, e.g., dioptric lens; used as a unit of refractive power measurement.
Emmetropia	The normal state of the eye with respect to refraction in which rays of light are entering the eye parallel to the optic axis and are brought to a focus exactly on the retina.
Esophoria	Inward deviation of the eye when it is covered and fusion prevented.
Exophoria	Outward deviation of the eye when it is covered and fusion prevented.
Heterophoria	Deviation of the eye when covered, preventing fusion.

Hyperopia	That error of refraction in which rays of light entering the eye parallel to the optic axis are brought to a focus behind the retina because the eyeball is too short from front to back (farsightedness).
Leptokurtic	A type of frequency distribution curve which is more peaked than the corresponding normal distribution curve, i.e., more values clustered about the mean than in a normal distribution curve.
Mesopic Vision	Vision with both rod and cone cells functioning.
Millilambert	A unit of brightness; 1/1000 of the value of 1 lambert (1 lumen/cm^2); 1 lambert is equal to $1/\pi$ candela/cm^2.
Miosis	Excessive contraction of the pupil.
Mydriasis	Dilation of the pupil.
Myopia	That error of refraction in which rays of light entering the eye parallel to the optic axis are brought to a focus in front of the retina because the eyeball is too long from front to back (near sightedness).
Parafoveal	The area of the retina containing both rod and cone photoreceptors that surrounds the fovea centralis.
Phoria	The direction of one eye, its line of sight, or some other reference axis, in relation to the other eye; manifested in the absence of an adequate fusion of visual stimuli, e.g., exophoria.

Photopic Vision	Vision in bright light with light adapted eyes believed to be mediated by the cones of the retina.
Protanopia	Defective color vision; specifically red color blindness.
Scotopic Vision	Vision under reduced illumination by the dark adapted eye in which the rod cells of the retina are the photo-receptors.
Strabismus	Deviation of the eye which cannot be overcome. The visual axes assume a position relative to each other different from that required for normal vision.
Trichromat	A person with normal color vision; the retina contains three types of cone cells that respond to red, green, or blue wavelengths, respectively.

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13. ABSTRACT

This report provides a comprehensive analysis of the significance of individual variation in human night vision capability. It reviews the origin and magnitude of inter- and intra-individual variation in the several physiological and behavioral processes that constitute dark adaptation and scotopic vision. The genetic, somatic, and behavioral factors that exhibit variation and the environmental factors affecting variation are discussed. The report identifies gaps in this knowledge that bear on the requirements for efficient night vision in the soldier. The report suggests that recognition of individual variation is critical to the concept of selecting key individuals for specific duties requiring night vision capability.

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Variation						