AD-A012 588

SELECTION OF INDIVIDUALS FOR SPECIFIC DUTIES ASSOCIATED WITH NIGHT VISION PROFICIENCY

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Federation of American Societies for Experimental Biology

Prepared for:

Air Force Office of Scientific Research
Advanced Research Projects Agency

February 1975

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR - TR - 75 - 0352
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER: AD-A012 588
4. TITLE (and Subtitle): Selection of Individuals for Specific Duties Associated With Night Vision Proficiency
5. TYPE OF REPORT & PERIOD COVERED: Technical
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): C. Jelleff Carr, Kenneth D. Fisher, John M. Talbot
8. CONTRACT OR GRANT NUMBER(s): F44620-74-C-0077
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Federation of American Societies for Experimental Biology* 9650 Rockville Pike, Bethesda, Md. 20014
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61101E ARPA order #2808 681312
11. CONTROLLING OFFICE NAME AND ADDRESS: Defense Advanced Research Projects Agency Arlington, Va. 22209**
12. REPORT DATE: February 1975
13. NUMBER OF PAGES: 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): DEPARTMENT OF THE AIR FORCE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (NL) 1400 WILSON BLVD ARLINGTON, VIRGINIA 22209
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*Life Sciences Research Office **Human Resources Research Office

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The human ability to see at night depends on the person's level of dark adaptation, his physiological state, as well as behavioral and environmental factors. There are major individual differences in night vision and the reasons for some differences are known; however, many are essentially unknown or unstudied. It is proposed that through the utilization of the refined techniques recently developed in the fields of vision, physiology, biochemistry and behavior, it may be possible to select

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This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Air Force Office of Scientific Research under Contract No. F44620-74-C-0077 (ARPA Order No. 2808; Program Code 4D20).

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FOREWORD

The Life Sciences Research Office (LSRO), Federation of American Societies for Experimental Biology (FASEB), provides scientific assessments of topics in the biomedical sciences. Reports are based upon comprehensive literature reviews and the scientific opinions of knowledgeable investigators engaged in research in specific areas of biology and medicine.

This technical report was prepared for the Human Resources Research Office, Defense Advanced Research Projects Agency (DARPA), Department of Defense, under contract number F44620-74-C-0077 monitored by the Air Force Office of Scientific Research.

The Life Sciences Research Office acknowledges the contributions of the investigators and consultants who have assisted with this study. The report reflects the opinions expressed by participants in meetings held at Beaumont House, FASEB, and other consultants. A judicious attempt has been made to incorporate the different views and opinions, however, the authors accept responsibility for the contents of the report. The listing of the consultants' names in Section VIII does not imply that they endorse the conclusions of the study.

The report has been reviewed and approved by the LSRO Advisory Committee (which consists of representatives of each constituent society of FASEB) under authority delegated by the Executive Committee of the Federation Board. Upon completion of these review procedures the report has been approved and transmitted to DARPA by the Executive Director, FASEB.

While this is a report of the Federation of American Societies for Experimental Biology, it does not necessarily reflect the opinion of all the individual members of its constituent societies.

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SUMMARY

The human ability to see at night depends on the person's level of dark adaptation, his physiological state, as well as behavioral and environmental factors. There are major individual differences in night vision and the reasons for some differences are known; however, many are essentially unknown or unstudied. It is proposed that through the utilization of the refined techniques recently developed in the fields of vision, physiology, biochemistry and behavior, it may be possible to select individuals for specific duties requiring night vision proficiency. To meet this goal an in-depth study of the subject is required to fully develop the concepts and the opportunities for future research.

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I. INTRODUCTION AND STATEMENT OF THE CONCEPT

Historically, individual differences in night vision proficiency and the speed and degree of dark adaptation have been of military and scientific interest. Numerous investigators have studied not only these individual variations but also the changing capacity to see at night and dark adapt that varies within the person from time to time. This subject received considerable attention during World War II and the following decade. Since that time, however, relatively few reports have appeared dealing with night vision and individual differences in performance with population data on young, healthy individuals. Techniques to identify traits that characterize superior, average, or inferior night vision may provide a ready basis for selection of individuals who must perform duties at low levels of luminance or near darkness.

The human capacity to see at night is notoriously inconsistent and depends on the individual's level of dark adaptation, his physiological state, and a number of behavioral factors. The efficiency of scotopic ability, or night vision, can be related to certain measurable influences, such as dietary vitamin A intake, occurrence of low grade infections, age, or effects of drugs. Other factors such as depth perception, prior exposure to bright light, noxious environmental agents, partial color blindness, and genetic metabolic abnormalities will also influence the quality of a person's night vision. Recognition and identification of the physiological, biochemical, and behavioral variations in individuals will materially assist in the understanding of the range of human night vision capability and its ramifications for human performance. These variables are likely correlated with other sensory abilities; however, few investigators have attempted to derive such interrelationships.

Work in these fields continues in a few laboratories but there does not appear to be a coordinated program that capitalizes upon research to implement previously known knowledge. The benefits include more efficient use of nocturnal tactical capabilities, selection of key individuals for specific tasks and exclusion of others, disclosure of disease, nutrition deficiencies and environmental contaminants, and prevention of their untoward effects.

A previous report on individual variability in dark adaptation and night vision in man reviewed studies through 1970 (Fisher and Carr, 1970). A more recent report emphasized the biological differences between men in their scotopic visual ability and enumerated several areas of research that might be pursued within the broad concept of biological individuality as related to an individual's performance in a military environment (Carr *et al.*, 1974).

Historically, it has been recognized that certain individuals have unusual abilities to perform well at night. Scouting talents are usually associated with superior night vision, intuitive perception of cues via the various sensory modalities, or some ill-defined awareness of the environmental dangers. In military situations these talents are highly desirable. In this report it is proposed that studies on night vision proficiency can be correlated with other physiological or biochemical parameters to determine if it is possible to use these latter criteria in the preselection of individuals for specific military duties. Readily measurable biological factors may assist in identifying the performance ability of an individual in addition to the well-recognized clinical test methods for the determination of night vision and dark adaptation. The current literature has been reviewed and laboratories and investigators working in these areas have been identified.

II. STUDIES OF NORMAL VARIATIONS

In an early study of normal subjects, Sheard (1944) observed that approximately 2 percent 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 ± 0.5-0.7 log unit of scotopic threshold in μ μ Lamberts. Similar observations have been made in populations of school children (Sheard, 1944) and adults (Sloan, 1947). With a well-trained subject and adequate control of both the environment and the test procedures, Sheard (1944) was able to reproduce dark-adaptation threshold values on the same subject from day to day within 0.1 log unit. Unfortunately, other studies are difficult to correlate with these older figures (Berry, 1949; Kinney, 1962; Sweeney *et al.*, 1959; Uhlaner and Zeidner, 1961). Most investigators comment on the influence of the cooperation of the subject in spite of the relatively objective nature of the test.

For example, the night vision sensitivity of 24 submariners, tested under prolonged restriction from sunlight during a 3-month continuous submerged cruise, revealed that seven individuals exhibited variable visual thresholds during dark-adaptation tests in the latter portion of the cruise, possibly correlating with low morale, and poor cooperation (Kinney, 1963). In related studies on only 3 individuals, scotopic sensitivity was found to be greatest in winter and lowest in summer (Sweeney *et al.*, 1960). The seasonal variations occur independently of individual differences; that is, the individual with the greatest scotopic sensitivity was always superior to the one with the lowest sensitivity, regardless of season. These observations confirm other studies that indicate night vision testing results may be complicated by recent previous exposure to sunlight, seasonal variation, or rapid movement from one latitude or hemisphere to another. In studies of these variations it can only be assumed that the diet of the test subjects contained an adequate supply of vitamins and other essential nutritional elements. These parameters were not tested by the investigators.

III. FACTORS INFLUENCING NIGHT VISION PROFICIENCY

Individual night vision sensitivity varies primarily with the amount of prior exposure of the person to light. The influence of illumination level or intensity on night vision appears reasonably well understood and has been standardized in testing situations. The glare phenomenon or a sudden bright illumination followed by a decreased illumination is an uncontrolled variable in dark-adaptation tests. This effect is similar to light "shock" on night vision. It is extremely difficult to study the effects of rapid changes in illumination under controlled conditions. In the "photostress test" or "macular dazzle test" Severin *et al.* (1963) showed that noxious agents and drugs increased the time required for recovery of visual acuity of the subject after exposure to a standardized light flash. In addition, individual depth perception is an important factor in night vision that has not been studied adequately under controlled conditions.

One of the better understood aspects of dark adaptation and night vision is the effect of aging. Average dark-adaptation proficiency declines with increasing age. This decrease becomes significant in most persons over 55-60 years of age (Percival and Meanock, 1968). These changes in visual acuity and dark-adaptive capability are believed to be related to progressive aging of the lens, retina, optic tract, and probably the higher central nervous system. McFarland *et al.* (1960) and other workers have concluded that age is highly correlated with dark-adaptation thresholds. McFarland (1970) in reviewing this subject suggested that aging associated with an impairment in oxygen availability to cerebral cortical tissues may account for the decline in dark-adaptation proficiency. The information available on the effects of carbon monoxide exposure and high altitudes (oxygen want) suggests similarities to the effects of aging on night vision. Individual differences are great and it could be argued that the progressive rise in dark-adaptive thresholds is frequently associated with other age-related phenomena such as senescence of the lens or the early stages of unrecognized cataracts.

Of importance in vision and especially in night vision, is the "visual load." This term refers to detection of very fine lines with poor contrast (maps) and low illumination. Thus the visual demands are increased significantly. It is recognized that age of the subject is exceedingly important in obtaining a high score and even 30 years of age may be too old for some individuals in such fine visual work (Fortuin, 1969). The challenge for the investigator is to discover those facts about the more youthful eye and central nervous system visual process that may be adapted to correcting the deficiencies of the older individual.

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 in the dark. The distribution of the individual thresholds at each determination showed close agreement with the theoretical normal distribution curve; 68 percent fell within 1 standard deviation (SD) of the normal curve, 95 percent within 2 SD, and 99.7 percent within 3 SD. Dark-adaptation thresholds of individuals beyond ± 2 SD were considered beyond the normal range; only 5 percent of the subjects were in this category. As expected, increase in threshold occurred with increasing age. Measurement of the normal deviation of an individual's variation in dark-adaptation threshold requires rigidly standardized methodology and experienced test subjects. Because there is a relatively wide range of individual variation in threshold, 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.

Individual metabolic differences now recognized in drug therapy and allergic states may be reflected in changes in the visual process or dark-adaptation thresholds. For example, Wilson (1965) reported that the thiocyanate present in body fluids may originate from the diet or from the detoxification of environmental traces of cyanide. The plasma concentration and urinary excretion of thiocyanate in smokers, as compared with nonsmokers, could be interpreted as related to cyanide exposure from tobacco smoke. If a person had an inborn error of cyanide metabolism and was unable to detoxify cyanide to thiocyanate, such a metabolic abnormality might exhibit itself as a neurological syndrome consistent with symptoms commonly associated with chronic cyanide exposure. This type of metabolic abnormality is illustrative of individual physiological or genetic variations that may influence such an exquisitely sensitive process as vision. The impairment in dark adaptation in mongols (Griffiths and Behrman, 1967) may be considered the result of an abnormal metabolic process. "Normal" subjects may have similar latent metabolic diseases that could produce visual modifications (Williams, 1956).

Any environmental situation that produced hypoxia will adversely influence night vision in all subjects and this phenomenon has been studied extensively (Fisher *et al.*, 1970). Vestibular stimulation associated with motion and the accompanying nystagmus have also been shown to adversely influence pilots ability to read cockpit instruments under low levels of illumination (Gilson *et al.*, 1970). All of these factors can be evaluated in terms of individual performance because some men are more or less susceptible to motion, hypoxia, or other noxious stimuli as these may be associated with a night vision task.

Visual light thresholds have been studied in neuropsychiatric patients as an objective measure of the perceptual distortions that these individuals experience. However, few studies report significant differences in thresholds between psychotic patients and normal controls. Nevertheless, in a study of dark adaptation in psychotic patients, Rubin and Stein (1960) found higher thresholds in psychotics than in normal individuals. Workers in this field have observed repeatedly that psychotic individuals experience autonomic nervous system imbalance (Wolin *et al.*, 1965). Pupillary responses alone, which vary significantly in psychotic patients, have been considered a clinical diagnostic criterion, and pupil fluctuations may explain some of the visual differences observed. These findings correlate with those of Kinney (1963) in normal men undergoing prolonged restriction from sunlight. The possible influence of emotional stress does not appear to have been studied for its effects on night vision but from the information at hand one would assume an adverse effect.

It is clear from the few instances cited in this report that night vision is influenced by many factors. Yet the range of variability is great and individuals with superior scotopic or mesopic vision could perform some tasks more efficiently than those lacking these abilities. Techniques to identify superior night vision capacity are available, and these should be coupled with assessment of performance abilities of individuals under conditions of low luminance.

IV. CURRENT RESEARCH IN THE FIELD

Because the human eye can discriminate light signals over an intensity range that is remarkable; about 10^{10}, it is understandable why individual differences in night vision proficiency can be expected (Rushton, 1965). Adaptation not only in the visual process itself but also the prior training and experience of the individual is extremely significant. For these reasons there have been numerous studies to measure the ranges of night vision ability among groups of individuals.

An 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 acitivites other than actual use of the night vision device involved partial or complete dark adaptation (Sternberg and Banks, 1970). In part, some differences may be related to proficiency in the use of the night vision device.

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 test scores on the 71 test subjects suggest considerable variation in individual responses to use of the simulated night vision device. According to Woodside and Dixon (1970) some individual differences are likely related to user beliefs as to the attributes of image intensifying night vision devices.

Stewart *et al.* (1968) reported that experimental drug induced miosis ("partial night blindness") 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. He studied the performance of the observers using unaided night vision alone and noted that each subject approached the target detection task with highly individualistic sensory skills, training, and intelligence. These characteristics will affect the quality of 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. Vicino (1970) also 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 prior skills, and abilities contribute significantly to observer performance. Unfortunately, important biological and physiological parameters were not measured in these men.

Vicino (1970) also 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. Studies of this type are specifically relevant to the understanding of performance of military tasks where night vision abilities are critical.

Hopkins (1970) has 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 skills 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 individual to see at night and his performance of military tasks.

Kobrick (1972) at the Army Research Institute of Environmental Medicine reported on the effects of mild to moderate hypoxia on response time to peripheral stimuli in the visual field during a task that involved stress (surveillance, vehicle operation or display monitoring). Beyond the stimulating effects of the task that assisted in maintaining alertness, there was a decrement in performance with increasing hypoxia. In the 10 male subjects there was wide individual variation. Unfortunately, no biochemical or physiological paramcters were measured.

A clinical glare tester has been developed to quantify glare sensitivity in patients (Miller *et al.*, 1972). This device might be adapted to standardize conditions for testing dark-adaptation in subjects where recovery times from glare exposure were to be measured. Only average figures are cited by the authors from studies on 10 normal subjects; however, large differences are recognized related to corneal clouding in numerous pathologic and nonpathologic conditions encountered in visual acuity testing programs.

Individual sensitivity to therapeutic drug effects on night vision has been noted previously (Carr *et al.*, 1969; Fisher and Carr, 1970). This is especially noteworthy for the antimalarial drug chloroquine. Gonasun and Potts (1974) have recently shown chloroquine to inhibit protein synthesis in the retinal pigment epithelium and this accounts in part for the retinopathy reported after use of the drug in high doses. No systematic study has been made of the night vision proficiency of subjects taking antimalarial doses of chloroquine or other antimalarials for long time periods.

These reports illustrate a few of the parameters that have been studied that demonstrate significant differences in individuals. Performance under the test conditions is influenced by motivation, vigilance and perhaps unrecognized by the person, the use of the periphery of the retina to achieve a high score on the test system. These factors are well recognized but difficult to standardize or quantify (Jerison, 1967; Low, 1946). Behavioral studies combined with physiological measures on poor and excellent responders in test situations as employed by workers in the field may prove fruitful. Fatigue, both acute and chronic, leads to a decrement in visual performance and measures have been developed to test this state as reflected in pupillary movements (Lowenstein *et al.*, 1963). It may prove useful to develop criteria of assessing "fatigue" in subjects by other methods in order that a correlation may be made with their night vision capability. Indeed, most studies on night vision have been concerned with pattern recognition, e.g., circles, squares, or patterns of relatively simple silhouette; however, the critical needs are for fine pattern recognition that has been called "texture" (Pickett, 1968). Techniques have been developed to study this factor in the application of a man's natural capacities for imagery analysis. Numerous aspects of the causes of individual variations in night vision proficiency are considered in publications dealing with vision and the sensitivity of the visual process in terms of the quantity of light required for the threshold detection or difference discrimination. These have been reviewed recently by Brown (1973). Unfortunately, most writers do not stress individual differences.

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VI. SUGGESTIONS FOR FUTURE RESEARCH

There is a need to develop a coordinated program of research on those aspects of night vision that include studies on techniques for the rapid and accurate determination of night vision of individuals and correlation of these data with various behavioral, physiological and biochemical variables.

Intensive study of those individuals who have poor or superior night vision abilities should reveal criteria that could be applied in selecting men for specific tasks and exclusion of others when nocturnal tactical capabilities are required.

A number of factors that influence night vision are recognized. Many of these can be controlled but the effects of aging on the visual apparatus, metabolic idiosyncrasies such as galactosemia, congenital pecularities such as steatorrhea preventing vitamin A absorption, and environmental influences require more investigation in order that the issues can be understood in terms of their influence on human performance.

It is remarkable that studies have not been made on the influence on night vision of impaired visual acuity, the transmissivity of spectacles and the usual visual aids employed for mesopic vision. Such investigations would be appropriate to assist in developing relatively simple criteria for selection of individuals for night vision tasks.

The refined techniques employed in recent investigations with human subjects in detecting the various factors that influence night vision proficiency should be utilized to study the effects of training, adaptation, motivation, vigilance and related behavioral phenomena along with the physiological measures.

The final utilization of the results of these studies would be application of this knowledge to the increased utilization of performance skills in meeting the demands of the military environment.

Few experiments on individual variability in night vision have stressed the value of having each subject serve as his own control. Investigators minimize individual variations by the use of a large number of individuals and this approach may lead to a loss of useful knowledge. Future studies should be addressed to quantifying the variables that influence a single subject.

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