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VISION RESEARCH IN MILITARY AND GOVERNMENT LABORATORIES (U)

John Lott Brown

Armed Forces—NRC Committee on Vision

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ARMED FORCES-NRC COMMITTEE ON VISION

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VISION RESEARCH IN MILITARY AND GOVERNMENT LABORATORIES

by

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INTRODUCTION

Fairly extensive research on a variety of aspects of vision is conducted within service laboratories in the Air Force, the Army, and the Navy. There is also some research on visual processes conducted in laboratories by the Coast Guard and by the National Aeronautics and Space Administration. Last year the Executive Secretary of the Armed Forces-NRC Committee on Vision requested information from a number of these laboratories concerning their in-house research. This report summarizes the results of that survey. References cited in this report include those received as a result of that survey. They are neither complete nor a representative sample of all the work in military laboratories.

SUMMARY OF LABORATORIES BY SERVICES

United States Air Force

In the Air Force, the greatest amount of vision research has been performed at the Aerospace Medical Research Laboratory of the Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Most of the research performed at Wright Field has been done by psychologists, and psychologists represent the largest number of researchers with interests in vision. Others are included in programs within physiology and biophysics. A number of individuals who are prominent in vision research have contributed to the program at Wright Field. They include C. A. Baker, Kenneth T. Brown, J. M. Christensen, A. Hyman, E. Marg, and W. J. White. Dr. Walter Grether has for many years played an important role both in research and in administrative activities at Wright Field.

Vision research is also performed at the Rome Air Development Center at Rome, New York. At Rome, concern is with ground support systems rather than with airborne systems, as at Wright-Patterson Air Force Base.

Some research in vision is performed at the Headquarters, Aerospace Medical Division, Brooks Air Force Base in Texas. Here the emphasis is on ophthalmological problems, rather than the psychophysical problems which are of greater concern to psychologists. The staff at Brooks Air Force Base includes four physicians, one Ph.D., and a number of supporting staff members with masters' and doctors' degrees.

United States Army

The Army is performing research in vision at a large number of locations. These include the Army Electronics Command at Fort Monmouth, New Jersey; the Optical Laboratory at Frankford Arsenal, Philadelphia; the Army Institute of Environmental Medicine at Natick, Massachusetts; the Army Engineering Laboratories at Aberdeen, Maryland; the Army Personnel Research Office in Washington, D. C.; the Medical Research Laboratory at Edgewood Arsenal, Maryland; Walter Reed Army Institute of Research, Washington, D. C.; the Eye Clinic, Walter Reed General Hospital, Washington, D. C.; the Geodesic Intelligence and Mapping Research and Development Agency, Fort Belvoir, Virginia; the Army Medical Research Laboratory at Fort Knox, Kentucky; the Medical Resources Research Office, Division No. 2 for Armor, at Fort Knox, Kentucky; the Army Aeromedical Research Unit at Fort Rucker, Alabama; and the Human Resources Research Office, Division No. 5 for Air Defense, at Fort Bliss, Texas. These Army laboratories employ approximately fifty scientists who are engaged full or part time in research in vision. Important work which has been performed at the Walter Reed laboratories includes the early years of microelectrode research performed by David Hubel, and the extensive work on electroretinography and psychophysical problems by John Armington and William Biersdorf. All of these individuals have now left Walter Reed and it is hoped that others will be able to maintain the research standards set by them. Significant research in vision has been coming from the laboratory at Fort Knox, Kentucky, over the years. A prime contributor to that research has been George Harker.

United States Navy

A number of Navy laboratories have been engaged in vision research for many years. The Navy Medical Research Laboratory at the Submarine Base, New London, Connecticut, has a distinguished history of research in vision which is currently being carried forward under the direction of Dr. Jo Ann Kinney. The work of Dean Farnsworth in the testing of color blindness and color specifications is well known. Forrest Dimmick, one of Titchener's last doctoral students, was for many years head of the Vision Branch at New London. Harry Sperling also made many significant contributions to the vision literature while at the New London laboratory.

Several other Navy laboratories perform significant research in vision. One is the Navy Aerospace Medical Institute of the Naval Aerospace Medical Center in Pensacola, Florida. Much of the research at Pensacola has been related to vestibulo-visual effects. This vision research at Pensacola has been influenced by a close association with Elek Ludvigh of the Kresge Eye Institute. Some of the work of James Miller was sponsored by the Kresge Eye Institute at Pensacola. Vision research at Pensacola is continued by Earl Miller

Vision research is performed at the Aviation Ordnance Department of the U. S. Naval Ordnance Test Station at China Lake, California. Much work has been done at the Aerospace Crew Equipment Laboratory of the Naval Air Engineering Center in Philadelphia on problems associated with instrument illumination and visibility with helmets and through visors. Research on vision as influenced by acceleration and high luminance is performed at the Aerospace Medical Acceleration Laboratory of the Naval Air Development Center at Johnsville, Pennsylvania. Research on the electrophysiology of vision has been performed at the Navy Medical Research Laboratory in Bethesda, Maryland. The work of Wagner and Wolbarsht on color vision in the fish is of considerable significance. Research in vision is also performed at the Navy Electronics Laboratory in San Diego and the Navy Research Laboratory in Anacostia, Maryland. The total number of professional personnel working primarily in vision in these laboratories numbers in the neighborhood of twenty-five.

The National Aeronautics and Space Administration

Although NASA is not a military organization, it is a supporter of the Armed Forces NAS-NRC Committee on Vision, and it is supporting significant research on vision in its own laboratories. It is therefore appropriate to include comments on the research performed within NASA laboratories in this report. These laboratories include those at the Ames Research Center at Moffett Field, California, the Electronics Center at Cambridge, Massachusetts, and and the Langley Research Center at Hampton, Virginia. There has been much interest and concern with visual problems at the Manned Spacecraft Center in Houston, Texas, as well, but the actual research program there is a very new one. There are approximately fifteen scientists concerned with visual studies in the various NASA centers.

Rather than attempt to review individually the research which has been performed in each of the laboratories cited above, treatment of the research in these laboratories will be organized in accordance with the kinds of problems which exist for the military and space problems.

THE NATURE OF MILITARY CONCERNS

Special Visual Problems Associated With Military Operations.

Problems associated with military procedures

There are a number of problems with important visual components which stem from special procedures employed in military operations.

Aircraft landing. The problem of aircraft landing remains a very important one in military operations where visual function is involved. The problem is more complicated at night and it is much more complicated in the Navy situation where the landing platform is the moving deck of an aircraft carrier. Much energy has been devoted to this problem. A number of aids have been developed in the form of lighting arrangements on the ground, as well as indicators in the cockpit. The mirror landing system has proven useful in carrier operations. The problem is of concern primarily to the Air Force and to the Navy but also to the Army. The Navy is supporting extensive work on the problem in industry, but there is relatively little of significance in the way of research being conducted in Navy laboratories themselves.

Low-altitude, high-speed flight. On many missions, it is advantageous for a military aircraft to fly at very high speeds at very low altitudes. The control problem is an extremely difficult one. It is rendered the more difficult by the jostling and vibration to which the pilot is subjected. These effects directly influence his visual capability. The ability to respond quickly to visual information input is essential in this kind of situation. The problem is a complex one, however, and at the present time there is apparently little experimental work being done within military laboratories themselves which is concerned primarily with visual problems as influenced by the vibrations which occur in low-altitude, high-speed flight.

Continuous visual control. The problem of flying an aircraft at low altitude and high speed is a special case of the general problem of visual control of maneuvers. Any continuous control function which is guided by visual cues may be included under this heading. There are several categories worthy of consideration. One of these is the remote control of a maneuvering unit by visual observation of the nature of the motion from a distance, or via remote indicators. Rendezvous and docking of space vehicles is another example of this general class of problem which is of great concern in the space program.

Over the years there has been some interest in what might be called direct visual tracking. This refers to the use of signals which are generated by the movements of the eyes themselves for control of a tracking system. The head may be held stationary and eye movements which occur when the observer closely follows a target object's motion may be used to maintain train on the object. The procedure would appear to be practical under certain circumstances and possibly superior to more conventional methods. NASA is currently supporting some research on this problem in industry.

Problems associated with the military environment

The nature of visual problems is in many ways influenced by the environment in which work must be done. Some special situations of particular military interest may be enumerated. One of these is the realm of high altitude flight. With virtually no outside visual reference, a pilot in the deplete visual world of high altitude may have difficulty with the detection of vehicles outside his own aircraft. This is attributed to "high altitude myopia." With no outside reference at a distance, the eyes are said to accommodate for a relatively short distance and those objects for which far accommodation would be appropriate are difficult to detect.

A variety of special problems which have been identified in connection with space flight have been reviewed by a number of authors. One important review of these problems has been edited by C. A. Baker, formerly at the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base (3). Two reviews of visual problems in space have been published by the National Academy of Sciences (8, 48). The visual experiences of astronauts and cosmonauts have been described and compared with predictions of man's visual capability made prior to space flight operations. A summary of flights up to 1963 has been presented by Donald Zink of the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, (63).

The low luminance environment encountered in night operations presents a variety of important problems connected with vision. These problems are the concern of aviators, ground forces, and lookouts aboard ship. Much energy has been devoted to their solution since before World War II. It may be of interest to point out here that the Army Personnel Research Office is currently initiating extensive work in night operations and night visual problems will be studied. This work is currently in the planning stage. The desirability of using spectrally selective illumination in circumstances where night vision must be preserved has been discussed at length in the literature. In many circumstances red light may be preferred. The problem is a complicated one, however, and it cannot be answered in general. Some reviews of this problem are referenced in the bibliography at the end of this report (4, 7, 9, 25, 52, 60).

There is ever-increasing national interest in problems relating to the oceans. Their military importance is, of course, of greatest concern to the Navy. The underwater environment represents special problems in vision for the diver and underwater swimmer.

Special stresses which influence vision

Military operations may subject men to a variety of circumstances which can be detrimental to vision. These may not be part of the regular environment but peculiar to certain military activities. An example is the effect on vision of an atomic flash. In any war which involved the use of nuclear weapons there would be extremely hazardous conditions for aviators, even when they were beyond the range of physical injury due to atomic weapon detonation. Even relatively short-term visual impairment might be catastrophic. This problem has been considered in air warfare research studies which assess the probabilities of mission success in relation to various tactics. Studies of the problem are also being sponsored by all branches of the armed services.

In space flight and in high altitude flight, the respiratory environment is maintained artificially. There are circumstances, however, when this respiratory environment may deviate significantly from the normal gas mixture which is available at the earth's surface. This is true in many cases where aviators are required to breathe with the aid of a mask, in pressure breathing systems which have been used, and in the case of divers. The difference in the respiratory environment may be in the direction either of increased partial pressure of oxygen or reduced partial pressure of oxygen. The effects of reduced partial pressure have been studied extensively over the years by the armed services, particularly by the Navy and the Air Force.

The effects of acceleration which accompany aircraft or space vehicle maneuvers, including exit and re-entry, may include effects on vision. This was recognized in the early days of flying and the problem has been studied extensively by flight surgeons for many years. The problem is still under investigation, and the Armed Forces have now been joined by NASA in its study.

Optical Aids.

A number of aids to vision have been devised for use by military personnel. One of the most recent is an image intensifier which permits observation at very low light levels without any artificial illumination. The device is thus quite different from the "snooperscope" of World War II which depended upon infrared illumination. The device works by amplifying the very low light levels available to a point where reasonably good vision is possible. Considerable success with these devices has been reported recently. Most of this work is being conducted by the Army although all of the services are interested. The device is classified and its detailed consideration is therefore not possible in this report.

Another area in which many devices have been under development recently has been in flash blindness protection. Protective devices include goggles which are designed to filter sufficient energy to prevent retinal damage and to minimize the duration of flash blindness. Such goggles present a problem, however. It is difficult to obtain adequate protection without wearing them all the time. When worn all the time they may reduce the light available in many situations to the point where they are unacceptable to operating personnel. Work has been performed on these devices by both the Air Force and the Navy. In addition to goggles which include fixed filters, other goggles have been developed which rapidly occlude light upon occurrence of a high-energy flash. When they operate rapidly enough they will preserve the vision of the wearer. Testing of flash blindness protective devices is a responsibility of the Aerospace Crew Equipment Laboratory at the Naval Air Engineering Center in Philadelphia.

Additional optical aids include binoculars, telescopes, and range finders. Some work is still being performed on these devices to improve them both in design and in the manner in which they are utilized. Work in this area has been of relatively limited scope in recent years, however.

An optical aid of considerable importance has been tested recently. That is a small light for the tip of helicopter blades which will permit the visualization of the blade path by pilots of other helicopters so that collision of blades may be avoided in flight. This device was developed at Fort Rucker, Alabama, by the Army.

Visual Displays.

With the increasing technological complexity of military weapons systems, the nature of visual displays becomes ever more complicated. The communication of information as rapidly and efficiently as possible from instrument faces on a panel in an aircraft cockpit, or control center, or any situation becomes more and more difficult as it becomes necessary to transmit more and more information. Although there has been some reduction in the number of fundamental studies on this topic in military laboratories within recent years, specific design of displays for new systems still occupies considerable effort, particularly in the Air Force and the Navy.

In designing visual displays, increasing attention has been paid in recent years to the advantages to be gained by presenting the information in a form analogous with the way it might be derived from viewing the real world. One result of this is the so-called "contact-analog" display which provides a two-dimensional rendering of three-dimensional perspective on a cathode ray screen. This was developed by the Army and the Navy. It would seem reasonable, and there is some evidence for the fact, that such displays would permit the avoidance of many of the errors which occur with abstract symbolic displays.

In any situation where displays are employed, be it a small aircraft cockpit or a large control space, lighting is of paramount importance for the viewing of such displays. The problem of spectrally selective illumination has already been cited. A controversy which had been restricted to the relative merits of red light versus white light has broadened with the fairly recent introduction of "lunar white light" by the Air Force. This is a light of relatively high color temperature equivalent, obtained by the use of a bluish filter. It is said to have the advantage of providing better contrast over a wider range of luminance levels than other lighting systems. Although this is one of the oldest military problems in vision it is still very much a concern. In addition to work in military laboratories, a number of contractors in industry and universities continue to work on the problem for various branches of the Armed Services. Recently, the Air Force requested a review of the problem of the spectral character of illumination by the Armed Forces-NRC Committee on Vision. This year the Advisory Group for Aeronautical Research and Development (AGARD) of NATO is attempting to organize a symposium on red versus white illumination for aircraft instruments and cockpit lighting (27). The introduction by the French of self-luminous materials which include tritium may require some investigation by reason of the possibility of radiation hazard.

LABORATORY RESEARCH

Research on vision in military laboratories covers a wide range of subjects and extends from studies of fundamental problems which may be of limited if any practical concern to highly applied research designed to provide immediate practical answers for operational problems. The material presented here has been divided, somewhat arbitrarily, between applied and basic research. Applied work probably represents the greatest volume of research performed in military laboratories, but it must be recognized that some of this is of considerable fundamental significance. On the other hand, basic research of the highest quality is performed in military laboratories and some of the results obtained in this research are of immediate practical importance for military operations.

Applied Research.

Search, detection, recognition, and reconnaissance. The simplest problem of search and detection from the standpoint of complexity within the visual field is probably that which confronts the pilot of a high altitude aircraft. The task of detecting a distant aircraft in an otherwise empty field may be an extremely difficult one, however. As indicated above, accommodation for relatively near objects may render it difficult to discriminate the minimal visual information available which is best seen with accommodation for infinity. The condition of the pilot under these circumstances has been labeled "space myopia," or high altitude myopia as mentioned above. This problem has been investigated by the Navy at Pensacola, Florida. The Navy is also concerned with the visibility of signal lights and markers which may be used in ship-to-ship communication and in air-sea rescue operations (53).

Problems associated with detection, recognition, and reconnaissance have probably occupied more of the attention of the Air Force than any other single area in vision in recent years. It has also been of concern to the Army, however. The Human Resources Research Office is concerned with the interpretation of images in reconnaissance photographs. The mapping group at Fort Belvoir, Virginia, has been brought into the area by the interest of its personnel in photogrammetry. The Army is interested in both air-to-ground and ground-to-air observation. These efforts are centered at Fort Rucker, Alabama, and Fort Bliss, Texas.

A large number of variables has been investigated fairly systematically in connection with problems of search and reconnaissance. At the Naval Ordnance Test Station at China Lake, Dr. Ronald Erickson has investigated the relation of search capability to visual noise, movement of the field, and its structure (18, 19, 20, 21, 22). He has also investigated a possible correlation between visual search time and peripheral visual acuity (17). A correlation was found for peripheral acuity measures made at 3.6 and 4.8 degrees of eccentricity, but not for 6 degrees of eccentricity.

An impressive volume of work on search and reconnaissance has come out of Wright-Patterson Air Force Base. Much of this work recently has been associated with the investigation of side-looking radar for reconnaissance. Some of the variables under consideration include the use of charts for briefing (39), the way in which the briefing is performed with respect to the time charts are available (57), whether they are available both before a flight and during a flight, and the width of the display (5). The basic variables include illumination, size of visual field under illumination, motion component, character of the background, and the size of the target (54, 13). In addition, contrast and color relationships are of obvious importance. All of these parameters have been investigated extensively. Scientists at the Rome Air Development Center of the Air Force have been concerned with aspects of these problems associated with photoreconnaissance.

In an effort to devise a quantitative method of predicting probabilities of detection against various backgrounds, a stimulus complexity analyzer has been developed for quantitative assessment of the background (51). The device would appear to be useful in evaluating detection probabilities.

A great deal of the research on search and reconnaissance as well as recognition has been performed by contractors. Some of this work has involved highly artificial displays in an attempt to get at the fundamentals of the technique of search which might be most efficient and some of the basic visual processes which underlie this function. Optical aids are frequently employed in search and reconnaissance operations. Two investigators are working at the optical laboratory at the Frankford Arsenal in Philadelphia to improve the advantage gained by using magnification combined with a large exit pupil in binoculars or other devices, particularly for night vision operations.

Search and reconnaissance present special problems associated with limitations on visibility underwater (35). The work on visibility at various depths and in various oceans has been supported by the Navy. Some of this work is coordinated by the Navy Laboratory at New London, Connecticut. Special lenses which may be useful for divers have been developed at the Navy Medical Laboratory at Johnsville, Pennsylvania. Their original purpose was not for divers, however. They were devised for the occupant of a liquid-filled device for protection against the forces of acceleration.

<u>Information displays</u>

The legibility of instruments and displays as related to their size, shape, contrast, and the design of characters on the faces of instruments, has been studied extensively. The relative probability of misinterpretation of any given display has also been a matter of great concern. Much of this work has been done at the Wright-Patterson Air Force Base. The Navy has conducted most of its research in this area at the Aerospace Crew Equipment Laboratory in Philadelphia. The problem is also of concern to the Army and several of the HUMRRO laboratories have worked in this area. The Electronics Research Center at NASA in Cambridge has recently undertaken an investigation of peripheral displays of information which can be interpreted by peripheral vision in order that an overall visual display might be constructed which will not require any sequential scanning for complete interpretation. The effectiveness of airborne television monitors has been a subject of evaluations conducted at the Naval Ordnance Test Station at China Lake (23, 24). The illumination of displays and interior lighting in general is studied at the Aerospace Crew Equipment Laboratory of the Navy in Philadelphia, and at the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base. These laboratories have played leading roles in the study of spectral characteristics of illumination in various military situations.

Night vision

Problems of interior illumination and night vision are not unrelated. Controversies over the use of red illumination arise out of the generally accepted advantages of red light for the preservation of dark adaptation (16, 34, 36). Controversies are based on the very real question as to whether advantages in dark adaptation gained by the use of red light may offset the disadvantages which are claimed for red light in certain situations. This controversy has been an exceedingly viable one and it can be expected to continue for some time.

Problems in night vision are probably of greatest importance for the Army which must use troops in the field under very low illumination conditions. Most of the research currently conducted on this problem is being sponsored by the Army. The U. S. Army Electronics Command at Fort Monmouth, New Jersey, is investigating a night vision simulator which permits control of luminance, contrast, distance and observation time. This may be used for studies and for training. The U. S. Army Human Engineering Laboratories in Aberdeen, Maryland, are investigating effects of intervening light sources on target obscuration. The possible value of drugs as aids to night vision is under investigation at the Army Aeromedical Research Unit at Fort Rucker, Alabama. Other studies are being conducted by HUMRRO Division 2 (Armor) at Fort Knox, Kentucky.

Flash blindness

Blindness which may be caused by an atomic flash has been a problem of great concern to the military services since the mid-1950's. The gravity of the problem prompted the Committee on Vision to devote an entire session to the topic at a recent annual meeting (1). A large amount of financial support has been given to research by university and industrial contractors both by the Air Force and by the Navy. Some military research is also being conducted. For the Air Force, some of this is sponsored by the Aerospace Medical Division at Brooks Air Force Base. Laboratory research has been supported by the Navy at the Naval Air Development Center at Johnsville (10). Laboratory studies have investigated recovery time as a function of the condition of flash adaptation (30, 33) and the nature of the task used as a criterion of recovery. Studies of the nature of the physical radiation have also been conducted (31) and the use of an eyepatch has been investigated (32). At the Navy Medical Research Institute at Bethesda, Maryland, the effects of retinal lesions caused by exposure to laser beams on visual acuity have been studied in pigeons and monkeys with the aid of an optokinetic technique (62). The Aerospace Crew Equipment Laboratory of the Navy in Philadelphia is adding the capability for flash blindness studies to a complex flight simulator in order to perform more realistic investigations of the effect of bright flashes on pilot performance. Some studies have been conducted by the Navy in flight with goggles which occlude vision entirely (6).

Various stresses

Effects of acceleration encountered in aircraft flight on vision were reported as early as 1929. The problem has been studied extensively in the laboratory with the aid of centrifuges. Earliest work was probably done by the Germans prior to World War II. In this country research was conducted at Wright Field by the Army Air Corps and at Pensacola by the Navy during World War II. Recently the problem has become one of interest to NASA. Prime concern has not been with vision necessarily, but visual decrement has been used widely as a criterion of acceleration effect. One of the earliest results of exposure to acceleration is dimming of vision and subsequent "blackout" without loss of consciousness. It has been demonstrated that relatively high acceleration forces can be tolerated when their line of action is perpendicular to an imagined column between the location of the heart and the eye. Blackout is clearly the result of an impaired circulation of blood to the eye and possibly to the brain. Recent studies of acceleration have been concerned to a greater extent with its effect on pilots' performance capability than with effects on vision. In space vehicles appropriate orientation is used to protect a pilot from acceleration forces insofar as they may influence visual processes.

Variation in the respiratory environment is probably of greatest concern to the Air Force and the Navy, but the Army has some interest in the problem as well. The recent tragedy in our space program has heightened concern over the use of one hundred percent oxygen atmospheres in space vehicles. Over the years, however, there has been greatest concern with the problem of reduced oxygen levels. German research and research in this country have demonstrated that with a reduction in the partial pressure of oxygen equivalent to an altitude of approximately 5,000 feet, visual symptoms can be detected. Research on this problem has been performed by the Air Force at Wright Field and other laboratories and by the Navy, most notably at Pensacola, Florida, and at New London, Connecticut. Additional research has been performed by the Navy at the Aerospace Crew Equipment Laboratory in Philadelphia and at the Naval Air Development Center at Johnsville, Pennsylvania. Recent Army interest in the problem has prompted a program of research at the Army Institute of Environmental Medicine at Natick, Massachusetts. Variables under investigation there include, among others, level of illumination and the use of drugs.

It is known that oxygen at higher than normal partial pressure can be toxic. It is probable that a 100 percent oxygen environment at sea level pressure would be lethal for most individuals within approximately seventy hours of exposure. There has not been convincing evidence that hyperbaric oxygen has any selective visual effect, however. The problem has been studied extensively by the Navy at the Aerospace Crew Equipment Laboratory (26). There, 100 percent oxygen atmospheres at pressures equivalent to altitudes of 27,000 and 18,000 feet as well as sea level were studied for varying durations. Maximum exposure was for 72 hours at the higher altitudes and for 24 hours at sea level. Visual acuity, color discrimination, stereopsis, critical flicker fusion frequency, vertical and lateral phoria, dark adaptation, the electroretinogram, and intraocular tensions were all measured. No effects were noted for exposures up to the maximum investigated. Hematological and other biochemical studies also showed no effect.

A variety of drugs are known to influence vision (61). Currently, the effects of chloroguine and other anti-malarial drugs are under investigation at Walter Reed in terms of their effects on the electroretinogram, electrooculogram, and various photo stress tests. So far no significant results have been reported.

Interference with visual function by vibration of the platform provided by a high-speed, low-altitude aircraft was mentioned above. Most of the studies of this problem have been performed by university or industrial contractors. Some work has been done at the Wright Air Development Center by the Air Force on a specially constructed device for the simulation of the motion patterns of an aircraft in vibration. Studies have also been performed on the Navy's centrifuge at Johnsville which was programmed to simulate the motion pattern associated with high-speed, low-altitude flight. Some experiments have been performed on mechanical vibration devices of the legibility of dials and other displays.

Visually guided continuous control functions

As mentioned above, one of the most important continuous control functions for which vision is the primary information source is the landing of an aircraft. Some laboratory studies of this problem have been conducted at various Air Force laboratories, particularly Wright Field, and in recent years by NASA, particularly at the Ames Research Center. The Navy's interest has been great but its research has been relatively limited. Laboratory studies usually depend upon the use of simulators. Visual cues and information are presented to the pilot with varying degrees of accuracy and pilot control manipulations result in feedback which are of greatest importance to the pilot in performing his task. Some efforts have been directed toward the question of whether certain visual capabilities which can be statically measured might be correlated with landing skills. Such things as visual acuity and visual light detection thresholds have not, so far, shown any important relation to a pilot's ability to execute the landing maneuver, however. A certain minimum visual acuity is, of course, required, but it is probable that information derived from the changing pattern within the visual field which accompanies motion is far more important. Consideration of these "dynamic" cues associated with changing perspective and monocular movement parallax effects was the subject of a session of the 1967 meeting of the Committee (2). A simulator which would appear to have great promise for the study of the problem was described by Aaron Hyman.

The remote control of a maneuvering element by visual observation has been studied at the Wright-Patterson Air Force Base by H. J. Clark in simulation with an on-off acceleration command control system (14). Three conditions of angular acceleration were investigated: 4, 8, and

12 degrees per second^2. Subjects uniformly preferred the 4 degree per second^2 rate for control of pitch, yaw and roll acceleration. Errors in roll were significantly greater than those in pitch and yaw, partly because of dependence in the roll control dimension on the horizon, which was not always in view. Pilots and non-pilots performed equally well but pilots could be trained faster than non-pilots.

In the realm of space flight, the rendezvous and docking of space vehicles represents a continuous control task which has been the subject of some simulator research conducted at the Langley Research Center in Virginia. Efforts have been made to determine how well the human observer can perform by direct visual contact. As our orbital program has demonstrated, this is a maneuver which can be performed quite satisfactorily.

It is evident that the use of simulators is quite important in a number of research areas. In recognition of the fact that information derived from dials and other indicators must be integrated into an overall pattern of information upon which actions are based in a continuous control situation, studies of instrument displays and lighting characteristics may now be performed within the context of an overall systems simulation. Simulators for a variety of investigations have been developed by the Air Force at Wright-Patterson Air Force Base (50) and by the Navy as well. Some quite sophisticated simulators have been developed in recent years by NASA at the Ames and Langley laboratories. A most elaborate simulation was that devised for the X-15 research aircraft in a joint project involving NASA and the Navy at the Navy's centrifuge installation at Johnsville, Pennsylvania. The X-15 instrument panel was duplicated in the gondola of the centrifuge and pilots were given a complete visual instrument display which responded to their control manipulations in addition to being exposed to a pattern of linear accelerations which was appropriate to the nature of the maneuvers performed (11).

Studies of what has been referred to above as direct visual tracking, where signals which reflect eye movement are used to effect control, have been conducted by the Navy both at China Lake and at the Navy Electronics Laboratory in San Diego.

Space flight

Several references have been cited above which review potential visual problems in space. The nature of these problems is a subject for speculation, but it is reasonable to assume that some aspects of the visual realm will differ in the space environment as compared to the terrestrial environment. At the Ames Research Center, a program of research has been instituted to investigate variations in apparent size as a function of luminance, the visibility of point sources and other visual characteristics of very simple stimuli in an atmosphere which is relatively free of any material which might cause dispersion or scattering of light (28, 29). The problem of solar glare and high contrast effects which may be encountered in the absence of any atmosphere has also been under consideration at the Ames Center.

At the Langley Research Center a number of visual simulations including a most elaborate one of the surface of the moon has been created both for research and for training in various aspects of the proposed space missions which will be dependent upon visual information. The Langley group has been interested in the possibility of making predictions as to how effectively man may be expected to perform a number of tasks in a space mission on the basis of fundamental information on vision, such as depth perception, the ability to discriminate rates of motion in depth as well as transverse to the line of sight, and light detection. Predictions from basic data are compared with results of simulator studies for a variety of problems including rendezvous and docking. A study of the space rendezvous problem where subjects are exclusively dependent upon visual clues has been conducted at the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base (12).

At Pensacola, the Navy has conducted a number of experiments on the possible effects of prolonged space flight on labyrinth mechanisms (46, 47). There has been some concern over the possibility that the absence of a gravitational field may alter utricular outputs in such a way that eye movements and their control may be influenced adversely. So far laboratory experiments provide no evidence that this will be the case.

<u>Special processing of visual information</u>

There are a variety of ways in which visual information may be processed. Differentiation and addition at boundaries may provide some sharpening of images. Techniques of spatial filtering provide ways of encoding as well as of recovering information. Some limited work related to these problems has been conducted in military laboratories, but most of the work of interest in this area has been performed in industrial or university laboratories. A session on this subject was included in the 1967 meeting of the Committee on Vision (2).

<u>Longitudinal studies</u>

All of the armed services are concerned with progressive changes in visual processes. Data are available on visual performance as measured on new recruits and newly commissioned officers, and some follow-up data are obtained over the years. Only limited use has been made of this information, however, and the necessary efforts to make it truly valuable have in general not been taken. An elaborate and potentially most informative longitudinal study which was initiated by the Federal Aviation Administration has recently been terminated for lack of funds. The potential value of much work done over a period of several years has therefore been lost to those with an interest in the problem. In the Army, studies are being conducted on changes in refractive error with aging at Fort Rucker, Alabama. It is hoped that the results may provide a basis for establishing standards for selection and retention of Army pilots.

Basic Visual Research.

Much fundamental research on vision of great value has come out of military laboratories. Where well-trained and competent scientists are employed, it is reasonable to expect them to maintain an interest in fundamental problems and to wish to explore experimental avenues which may occur to them as a result of their applied work. Actually, many military laboratories provide an assurance to the newly recruited scientist that he may use 20% or more of his time for research of his own devising without reference to its possible application for military operations. It would be difficult or impossible to persuade many of our best scientists to work in military laboratories without some such assurance. In vision, fundamental research covers many areas and the information presented below is highly selective. It will, however, provide some indication of the nature of the work which has been performed.

Psychophysical studies of vision

Over the years, dark adaptation, night vision, and associated problems have been studied as extensively as almost any problem in military laboratories. Many of the experiments are quite fundamental, but it is clear that this is one area in which there is little if any gap between applied and basic experiments. Many of the results of the most fundamental experiments have relevance in military operations.

Color vision has also been given much attention. Highly significant research in this area has come out of the Navy Medical Research Laboratory at New London from the programs of both Dimmick and Farnsworth. Significant work continues, as mentioned above, under the direction of Dr. JoAnn Kinney (37). Work on the spectral sensitivity of the visual process in man and animals has been studied extensively at the Walter Reed Laboratory by Armington and his associates. At Fort Knox, Army scientists are studying visual acuity as a function of wavelength of the illuminant. Color naming and color discrimination are subjects of concern to visual scientists at the Edgewood Arsenal. At Fort Rucker, Alabama, an experiment is planned in which just-noticeable differences in hue will be measured as a function of wavelength for the 10° field. At the Ames Laboratory of NASA, Mary Connors, formerly at the Navy Laboratory in New London, is studying color detection thresholds as a function of target size and the duration of presentation.

A variety of experiments on many topics has been conducted in military laboratories (38, 49, 58). Many reports have appeared from the Army Laboratory in Fort Knox on the Pulfrich phenomenon. Experiments have also been performed there on various problems in depth perception. Extensive work has been performed over the years by three laboratories primarily: the Navy Medical Research Laboratory at New London, the Army Medical Research Laboratory at Walter Reed, and the Wright Aerospace Medical Laboratory at Wright-Patterson Air Force Base.

Electrophysiology

Studies of the electrophysiology of vision have come out of two military laboratories in particular. These are the Army laboratory at Walter Reed and the Navy Medical Research Institute laboratory at Bethesda. At Walter Reed, Armington and Biersdorf and their associates have studied a variety of aspects of the electroretinogram in man and in animals in relation to spectral and other characteristics of the stimulus. As mentioned above, Hubel's single-cell studies of visual response to a variety of stimuli were begun at the Walter Reed laboratory. For the Navy, the work of Wagner, Wolbarsht, and their associates on the visual response in the retinas of fish to various wavelengths of stimulation represents a classic contribution in the area of comparative color vision. This work is continuing at the Navy Medical Research Institute (59). Studies of evoked potentials and the electroretinogram have also been conducted at the Navy Electronics Laboratory in San Diego under the direction of Carroll White and at the Naval Air Development Center in Johnsville, Pennsylvania. Experiments are currently under way at the Army Laboratory at Fort Knox investigating the responses of single cells in the lateral geniculate body of the primate to various stimulating wavelengths.

Oculo-vestibular effects

Important and most fundamental experiments on the oculo-vestibular responses have been conducted at two military laboratories: the Aerospace Medical Laboratory at Pensacola, Florida, of the Navy (40, 41, 43), and the Medical Research Laboratory of the Army at Fort Knox, Kentucky. Work at Pensacola has been under the direction of Captain Ashton Graybiel, F. Guedry, and others. The work at Fort Knox also owes much to the efforts of Guedry who spent a number of years there prior to going to Pensacola.

Other vision research

A review of various bibliographies which are available on military research (e.g. 55) will provide extensive additional information on experiments which have been conducted in a number of military laboratories. These extend from fundamental psychophysical and electrophysiological experiments to fairly complex studies of perceptual processes. Some interesting work in the latter category has been undertaken at the Aerospace Crew Equipment Laboratory of the Navy in Philadelphia (15). Perception of the vertical and horizontal has been investigated as this may be influenced by other sensory inputs (42, 44, 45). These include vestibular and kinesthetic cues. Results suggest important interactions between various sensory inputs in the perceptual response of the observer.

STANDARDS, TESTING, AND SCREENING

The problem of determining the minimum acceptable visual performance for a given kind of military duty and the establishment of appropriate tests and screening devices to ensure that candidates for military service are capable of such performance rests with the military laboratories themselves. Standards have evolved over the years and selective standards have been developed for such jobs as the piloting of aircraft. Standards are not uniform across all services. In some cases they may be too stringent, in others, too lax. They are subject to continuing change with development of new information. Notable among tests developed by the services are the color vision tests of Farnsworth developed for the Navy at New London and a recent night vision tester developed by HUMRRO for the Army (56). The suitability of contact lenses for military personnel in various occupations is a current subject for debate. In general, they are not considered satisfactory for aviators. Currently, there is also debate on the desirability of dilating the pupil for routine refractions. Advocates of the desirability of good longitudinal data collection tend to favor pupil dilation so that maximum possible information may be obtained.

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