THE VISUAL STANDARDS FOR THE SELECTION
AND RETENTION OF ASTRONAUTS

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Prepared under Contract No. NAS 9-9665 by
INDIANA UNIVERSITY
DIVISION OF OPTOMETRY AND
PROGRAM IN PHYSIOLOGICAL OPTICS
BLOOMINGTON, INDIANA
for Manned Spacecraft Center, Houston, Texas
National Aeronautics and Space Administration

June 1970

1. Astronauts
2. Eyes and Locomotion
3. Visual Perception
The Visual Standards for the Selection and Retention of Astronauts
Contract No. NAS 9-9665
June 1970

The purpose of this research is to determine the origin and adequacy of the vision standards being used for the selection and retention of astronauts and scientist astronauts. A broad based literature search was carried out to evaluate the adequacy of the present vision test standards which are summarized in Table I.

The scope of the literature search is indicated by the following list of topics covered.

I. Atmospheric Effects
II. Bibliographies of Related Visual Research
III. Color Vision
IV. Contrast Thresholds
V. Dark Adaptation
VI. Depth Perception and Stereopsis
VII. Displays and Visual Simulation
VIII. Effects of Vibration
IX. Flash Blindness, Glare and Radiation Effects
X. Flicker Fusion Frequency
XI. Hardware, Including Ophthalmic Instruments
XII. Illusions and Visual Perception
   i. Anisokokias
   ii. Autokokias
   iii. Cyclotorsional Eye Movements
The voluminous literature is indicated by the abstracts included in this report. The coverage of the literature is not exhaustive but it does include the main publications on vision standards for aviators. From the literature it is apparent that many of the vision tests and procedures are inadequate or out dated and that certain physiological aspects of vision that are of importance to aviators and astronauts have been neglected or overlooked. The primary oversight of immediate concern in this report relates to testing for near vision capabilities.

Testing for distance vision function has been the main concern in the past. Yet in modern aviation and in space flight, near vision has risen to high importance while distance vision has become almost unnecessary. The vision tests indicated in Table I could be passed even by a person with a strabismus at the near point, and hence are grossly incapable of identifying those people who have near point heterophorias of significance or accommodative problems at near. Furthermore, to compound
the problem, the maturation of pilots and astronauts ultimately brings them into the age of presbyopia wherein accommodative and related near point heterophoria problems become acute.

The nature of many of the tests in Table I is such that pre-coaching by fellow cadets or past experience and common sense can allow an otherwise unqualified person to pass the tests. A need exists therefore to make the testing more objective. Alternatively, greater control over subjective techniques is needed to ensure reliable reporting of the vision status of the examinees.

It is recommended that for improvements in standards, further investigation and experimental work be carried out on the need for and methods of testing that might be used in the following areas.

- Functional amplitudes at distance and near
- Fixation disparity at distance and near, a test which might be able to supplement the need for fusion tests
- Visual functions of dynamic acuity and stereopsis
- Ocular motility and muscle fields
- Near point of convergence
- Dynamic accommodation responsiveness
- Amplitude of accommodation needed for prolonged efficient visual performance.

While changes in vision testing are indicated, it is perhaps premature to recommend them at this time. The areas most in need of revision and expansion also need more documentation and research which is programmed for the next year. The following section covers the literature abstracted.

I. ATMOSPHERIC EFFECTS

1918 U.S. WAR DEPARTMENT AIR SERVICE MEDICAL


Pilots were classified into one of three altitudes at which they were supposedly safe based on tests to determine their ability to sustain anoxia. These tests included the Dreyer apparatus, Flack bag and rebreathing apparatus. Pictures and descriptions are given of each. Low oxygen has a marked effect on any defect of the eyes.

Also see abstract under Depth Perception and Stereopsis.

1944 STONE, R.C.

THE EFFECT OF EXHAUSTION AND MODERATE ANOXIA ON OCULAR MUSCLE BALANCE


The heterophorias of 14 aviation cadets, all with apparently 1° of hyperphoria, were measured before and after severe physical fatigue and moderately severe anoxia. No significant increase in vertical heterophoria was found. It also appears that the horizontal phorias were insignificantly affected.

1952 CEBIS, P.A.

RETINAL ADAPTATION IN NIGHT FLYING


The temporary loss of the ability to see the horizon on dark nights reported by experienced pilots is enhanced during oxygen deficiency.

Also see abstract under Dark Adaptation.

1953 McPARDLE, ROSS A.

HUMAN FACTORS IN AIR TRANSPORTATION


Page 157: Table of physical characteristics of the standard atmosphere.

Also see abstract under Illusions and Visual Interaction: Aniseikonia.
1963 HANT, R.M.

**effects of outer space environment important to simulation of space vehicles**


A literature search was carried out to delineate the effects that need to be incorporated into a simulator to adequately simulate the external space environment, and thereby analyze the effects on the crew and vehicle. Recommendations for further studies are given.

1962 MASTERS, R.L.

**the effects of alcohol and anoxia on the retinopodias (thesis)**


Extensive review of the literature. Summary of effects:

Alcohol—results in cephaloplia at distance and exophoria at near, with a neutral point in alcohol effect somewhere in between. Various explanations are proposed.

Anoxia—much more disagreement than with alcohol. Most workers note an increase in exophoria at distance with altitude, while the situation at near is more controversial.

1963 LACHMANN, J.M.

**space cabin atmosphere trace contaminants and their possible implication on visual parameters**


Ozone can cause marked changes in several visual parameters. It has been shown to be present in the cockpit and passenger cabins of jet airliners in sufficient concentrations to cause visual effects in the laboratory, when flying in the lowest regions of the ionosphere (references given in support). It is also considered that ionized human waste may become highly toxic in gaseous or volatile form. Twenty-eight subjects were exposed for 3 and 6 hours to three different concentrations of ozone, namely 20 ppm, 35 ppm and 50 ppm by volume. From 3624 vision tests it is shown that photopic visual acuity, stereopsis, vertical phoria and color vision were not affected. Subjectivities changed 0-4 1/2° relatively more eso- or eso- however, while prism divergence and convergence also showed marked changes. Perimeter tests showed average increase in field. Scotopic vision was affected in every case. The possibility of contamination formation in spacecraft and the affects on vision are discussed at length.

1959 SIMMONS, B.C.

**selection of a sealed cabin atmosphere**

Archbold, E.R.


High altitude balloon capsules give data to design a sealed cabin to operate at space equivalent altitudes. Physical variables to be considered are outlined. Atmosphere should provide for no performance decrement rather than for comfort or survival. Discussion of liquid oxygen converters, selection of cabin pressure with relation to "bends", combustibility of atmosphere. The possible use of helium as replacement for nitrogen was proposed.

1958 MILLER, R.P.

**effect of breathing 100% oxygen at atmospheric pressure upon the visual field and visual acuity**


Effect measured on central and peripheral fields and visual acuity measured using tangent screen, perimeter and Details acuity Meter. Results showed no decrement under the conditions stated for a period of over 4 hours.

1959 LENTS, J.I.

**observations on mice exposed to cosmic radiation in the stratosphere: a longevity and pathological study of 85 mice**


A study of the biological effects of a 24 hour exposure to primary cosmic radiation was carried on on 85 mice launched in August 1955. The animals were at about 50,000 feet for 10 hours where they were subjected to be hit by 3750 thin-down particles. Control mice on the ground were subjected to the same rigors as the, experimental mice, and both experimental and control mice were allowed to live out their life-spans. Results indicate that there were no significant effects on the days exposure to light and medium-weight primary cosmic particles in the stratosphere had any long term adverse effect.

1953 SIMMONS, L.C.

**effect of oxygen deficiency and various other factors in color saturation thresholds**


Using a color saturation threshold meter, the effects of hypoxia, alcohol, and coffee were studied on the saturation thresholds of red, green, and blue. Hypoxia up to an altitude of 18,000 feet had a very small effect on color saturation thresholds, deteriorating recognition of green and blue to a barely significant extent. Alcohol corresponding to 60 cc's of absolute alcohol impaired recognition of all three colors. Coffee improved the recognition of red and blue.

1959 SIMMONS, D.C.

**selection of a sealed cabin atmosphere**

Archbold, E.R.


High altitude balloon capsules give data to design a sealed cabin to operate at space equivalent altitudes. Physical variables to be considered are outlined. Atmosphere should provide for no
OXYGEN BREATHING EFFECTS UPON NIGHT VISION THRESHOLDS


Rod and cone night vision thresholds were measured while breathing oxygen at one atmosphere for periods up to 140 minutes and at 2.83 atm. for 20 minutes. One of the five subjects showed elevated thresholds at 1 atm. and two of the remaining four at 2.83 atm. Both rod and cone thresholds were lower (more sensitive) after fasting subjects ingested 100 grams of glucose while breathing oxygen at 1 atm... enhanced the night vision sensitivity of one fasting subject. Six of eight showed a small decrement in night vision sensitivity while breathing environmental air.

EFFECT ON VISION OF REPEATED EXPOSURE TO CO2


Visual effects of repeated exposure to CO2 at levels commonly regarded as innocuous were investigated. Exposure varied cyclically from 0.02% (air) to 3.00% at one atmospheric pressure every 24 hours for 6 days. A battery of visual tests was administered during this period and in control periods both before and after the exposure to CO2. Among the various tests, night vision sensitivity and color vision for green were the only ones which repeatedly detected impairment of efficiency during the period of exposure. All other visual functions tested remained normal.

BIBLIOGRAPHIES

1939 McFARLAND, ROSS A. BIBLIOGRAPHY ON THE SELECTION, TRAINING AND PHYSICAL FITNESS OF AVIATION PILOTS


Complete bibliography to 1939. Contents include:

I. Psychological studies.
II. Sensorial tests.
III. Physiological studies.
IV. Effects of moderate and high altitudes.
V. Medical examinations and tests of physical fitness.
VI. Human factors in airplane accidents.
VII. List of aeronautical journals.

1960 NOTTING, C.O. DISPLAY AND CONTROL REQUIREMENTS FOR MANNED SPACE FLIGHT

Anderson, M.J.


Includes a large bibliography.

Sea abstract under Displays and Visual Simulation.

OPTICS AND VISUAL PHYSIOLOGY (ANNUAL REVIEW)


Includes foreign titles.

INDEX OF AEROSPACE MEDICAL RESEARCH REPORTS PUBLISHED DURING THE PERIOD SEPTEMBER 1959-DECEMBER 1961


BIBLIOGRAPHY OF RESEARCH REPORTS AND PUBLICATIONS ISSUED BY THE BIODYNAMICS AND BIONICS DIVISION

1963 6570th AEROSPACE MEDICAL RESEARCH LABORATORIES
INDEX OF AEROSPACE MEDICAL RESEARCH REPORTS

1963 STEAMER, P.R.
CATALOG OF SCIENTIFIC PUBLICATIONS 1942-1963
Classified into current research, inactive subtasks, terminated projects, joint reports, etc.

1966 AEROSPACE MEDICAL RESEARCH LABORATORIES
INDEX OF AEROSPACE MEDICAL RESEARCH LABORATORIES REPORTS: APRIL-UPR NO. 63-1 THROUGH APRIL-UPR NO. 63-137
Abstracts of reports by project and task are included.

1966 STEVENSON, S.A.
A BIBLIOGRAPHY OF REPORTS ISSUED BY THE BEHAVIORAL SCIENCES LABORATORY: APRIL 1946-DECEMBER 1965
Includes engineering psychology, training psychology, environmental stress, simulation techniques and physical anthropology.

1967 STEVENSON, S.A.
1966 SUPPLEMENT TO A BIBLIOGRAPHY OF REPORTS ISSUED BY THE BEHAVIORAL SCIENCES LABORATORY

1968 KASPAR, C.P.
ANOTATED BIBLIOGRAPHY OF REPORTS ISSUED BY THE NAVAL AEROSPACE MEDICAL INSTITUTE, PENSACOLA, FLORIDA: 1 JANUARY 1964-1 JULY 1965
III. COLOR VISION

1931 COOPER et al. DEPARTMENT OF COMMERCE CONFERENCE

This paper concerns a group of vision experts discussing the visual requirements for the aviation medical examination. It was suggested that men should not be disqualified merely for misaligning a couple of Ishihara plates; also several copies of the National Geographic were useful in final testing.

1936 WHITE, M.S. TESTS FOR COLOR BLINDNESS

Extremely good review of the work and visual tests up to 1936 is presented; color deficiencies are also classified. It appears that no one test was used for color vision testing but, "the ideal method of attacking the problem is to supplement one test with the other." England was using the Edridge-Green lantern.

1942 WHITE, M.S. A STUDY OF THE VALUE OF THE PSEUDO-ISOCROMATIC COLOR VISION TEST IN THE SELECTION OF THE MILITARY PILOT

It was concluded that the tests used in pilot selection for color vision screening were unreliable. The Ishihara test is adequate and should become standard selection procedure.

1951 FARRSWORTH, D. PROPOSED ARMED FORCES COLOR VISION TEST FOR SCREENING

Fifteen pseudo-isochromatic plates were selected from the Amer. Opt. Co. selection (14 diagnostic, 1 demonstration). These were 99% effective but the number of plates that failed bears no relation to the degree of deficiency. Specifications given for standard viewing lamp.

1953 SCHWERTZ, E. EFFECT OF OXYGEN DEFICIENCY AND VARIOUS OTHER FACTORS ON COLOR SATURATION THRESHOLDS

See abstract under Atmospheric Effects.

1959 SCHWERTZ, E. VISION AND ASTRONAUTICS

Visibility of colors depends on the area and luminance of the observed area. Threshold illumination for correct recognition of colors is about 10 lux; this is equivalent to a distance from the sun of about 3 times the distance of the planet Pluto from the sun. The eyes must be light adapted; if the astronaut scans the sky he becomes dark adapted and a Purkinje shift results.

1962 MILLER, J.H. (Editor) VISUAL PROBLEMS OF SPACE TRAVEL

Papers 3-4: Description of colors seen on launching and in space. Also see abstract under Space Flight Including Reconnaissance and Surveillance.

1968 WHITCOMB, E.A. THE MEASUREMENT OF VISUAL FUNCTION (SYMPOSIUM) PROCEEDINGS OF SPRING MEETING 1965

The papers on color vision include a description of the 100 hue test and a short discussion of the laboratory measurement of color vision.

1969 WEITZMAN, D.O. EFFECT ON VISION OF REPEATED EXPOSURE TO CO2

Color vision for green showed a repeatedly detectable impairment of
efficiency during a period of exposure to CO₂ at levels commonly regarded as innocuous. The exposure varied cyclically from 0.06 X (i.e. air) to 3.01 at one atmospheric pressure every 24 hours for 6 days.

Also see abstract under Atmospheric Effects.

1969 MILLER, R.D. RESEARCH ON VISUAL PROBLEMS IN SPACE FLIGHT et. al.


The work covers the investigation of the optical parameters of the Apollo pressure suit helmet and visors and the effect of optical distortions upon visual performance. The primary visual function investigated is binocular depth perception. Results are also included of work done on photodarstellung due to exposure to U-V radiation and the effect of the gold coated lexan visor on color perception.

Also see abstract under Depth Perception and Stereopsis.

1946 BLACKWELL, B.B. CONTRAST THRESHOLDS OF THE HUMAN EYE


Experimental data are presented representing approximately 450,000 responses made by trained observers under laboratory conditions (2,000,000 were actually recorded). Contrast thresholds are presented for stimuli brighter and darker than their background, and for 20 values of stimulus exposure. In each case wide variations were studied in the parameters; stimulus contrast, stimulus area and adaptation brightness.

1956 LINFORD, E.B. TRANSMISSION FACTORS AND OPTICAL DESIGN


This paper is concerned with formulating the requirements which must be fulfilled by a realistic theory of optical image evaluation, and with the analytical techniques which enable these requirements to be met to a greater or lesser extent. Some of the shortcomings of old and present-day methods of image assessment are enumerated and the above-mentioned requirements are outlined. The Fourier treatment of optical images is extended to cover systems of fairly large aperture and field, working in polychromatic light, and the basic properties of their transmission factors (response functions) are developed. The evaluation of optical images and of optical designs is discussed in terms of these transmission factors.

1956 SCHADE, O.H., JR. OPTICAL AND PHOTOELECTRIC ANALOG OF THE EYE


A photoelectric analog of the visual system is constructed in conformance with anatomical data. The analog has the form of a color television camera chain feeding electrical signals to a "computer" (the brain). Evaluation of characteristics is limited to elements preceding the computer, and particularly to the "luminance channel" of the color system. The primary photoelectric transfer characteristics of the receptors (rods and cones) are computed as a function of retinal illumination from threshold signal-to-noise ratios in the effective image area of point sources, disks, and other test objects. The effective image area, which is the convolution of the sensor area with the sampling area of the visual system, is determined from its Fourier spectrum. The constants of the transfer functions are established from the optical constants of the eye, its storage-time function, and the pathways of its statistical units of the rod and cone systems. There is little room for variation of constants, if they are to remain in agreement with observed values. The incomplete dc restoration in the
system (differentiation of edges) is taken into account as a negative image component caused by feedback. System design principles are used as a guide in calculating the signal integration by retinal elements and the relative photoconductor gain characteristics of the receptors which are part of a system of interdependent functions including the primary characteristic, the over-all transfer characteristic to the optic nerve lines, and the four spatial integration characteristics represented by the equivalent passbands of lens and retina for the rod and cone systems. The final solution is perhaps not completely unique for all functions, but does not violate or disagree with fundamental principles or observations as demonstrated by a comparison of the operating characteristic of the analog with the Raussell lightness scale, its noise level with the perception of external noise; and its statistical transfer function, relative gain, gamma, and feedback with observed data. The acuity, contrast sensitivity, and threshold visibility of point sources of the analog are, of course, in agreement with corresponding properties of the eye.

1956 VOOG, J.J.
Light BEHAVIOR
Rouam, M.A.
Contrast thresholds—measured with dots and Landolt rings—are given as a function of object size and brightness for 31 observers. The desirability of presenting upper and lower limiting threshold curves is pointed out. Differences with the experiments of Blackwell are discussed. The influence of training is shown to be negligible.

1958 SCHAEDL, O.H.
ON THE QUALITY OF COLOR-TELEVISION IMAGES
AND THE PERCEPTION OF COLOR DETAIL
A theoretical and experimental study of the NTSC color system, supported by color photographs, shows that contrast range and color saturation obtained with commercial tricolor kinescopes provide a larger color space than provided by color motion pictures. In fine detail more than 60 per cent of full color information is transmitted and reproduced by the NTSC system because the bandwidth restrictions of the electrical color signals (I, Q) do not affect definition in the vertical dimension and have a smaller effect on the reproduction of horizontal color detail than indicated by earlier evaluations which disregarded the two-dimensional nature of the image. The detail color reproduction appears adequate to the eye because the color errors remaining, although perceptible, are small. This fact is significant because the spatial sine-wave response functions of the color discriminators of the visual system are found to be substantially independent of the color of light and similar to the spatial sine-wave luminance response function of the eye.

1958 VOG, J.J.
LIGHT BEHAVIOR
Rouam, M.A.
Part I of this series described a method which yielded the sine-wave response of the complete visual system by assuming that the Mach phenomenon is the result of a convolution, in the optical sense, of the object luminance distribution with the effective spread-function of the visual system. This second paper is concerned with measuring the response of the visual system to sine-wave and square-wave spatial distributions using the threshold criterion of contrast sensitivity. Particular emphasis is placed on the low spatial frequencies, a region which is believed to be critically important in the mechanism of visual contrast phenomena. Results strongly imply interaction of two basic mechanisms in the visual system. These mechanisms may be characterized individually as a low-pass filter component (optical) and a high-pass filter component (neural, chemical, electrical, etc.).

1962 KRAHNKEFF, J.
LIGHT DISTRIBUTION IN HUMAN RETINAL IMAGES
The image-forming properties of the human optical system have been examined with the aid of a photoelectric ophthalmoscope. The light distributions in images of bright vertical lines formed by a double passageway through the eye optics were measured. On the assumption that the eye optics are reversible, the light distributions on the retina were computed by means of Fourier transforms. The results are also expressed in terms of the spatial frequency response functions for the eye. The effects of pupil size were examined. The best acuity was obtained with a 5 mm pupil. The results confirm the earlier measurements on human eyes reported by Blakemore. The more recent experiments on animal material by DeMoor do not seem to be relevant to living human eyes.

1962 WOLFE, R.H.
WIDTH OF THE HUMAN VISUAL SPREAD FUNCTION AS DETERMINED PSYCHOMETRICALLY
The response of the human visual system to an optical image is assumed to be linearly related to the logarithm of the spread function of the photographic system projected onto the retina combined with the spread function of the visual system. From psychophysical data derived from viewing (at different distances) a series of pictures generated with different spread functions, an optimum is obtained of the variance of the spread function of the visual system. The square root of this variance ranges from 3λ to 8λ, depending on the techniques used and on the training of the
1962  VESTREKING, C.  LIGHT DISTRIBUTION IN THE IMAGE FORMED BY THE LIVING HUMAN EYE

By photelastic scanning, the light distribution was determined in the aerial ophthalmoscopic image of a thin light filament viewed by an observer with an homotroplized eye. Light distributions were obtained for various pupil sizes and degrees of defocusing. Measurements were also obtained with bar and grating objects. To compute the line-spread function on the fundus, correction was made for the double passage of the light through the optical system of the eye on the assumption that the spread in angular measure is the same in both directions. The results may be considered to depict distributions which are possibly broader, but certainly not narrower, than the real distributions in the retinal image. The line-spread function on the fundus was determined to have a half-width at half-height of one minute of arc for an eye in best focus with a 3 mm pupil, and this suggests that the point-spread function has half-width 0.66 minute of arc as an upper estimate.

1963  VESTREKING, C.  OPTICAL AND MOTOR FACTORS IN THE FORMATION OF THE RETINAL IMAGE

Recent work on eye movement, pupil and accommodation responses in reviewed with emphasis on the relevance of the results to retinal-image formation. Diffraction, chromatic, optical aberration, and transmission characteristics of the eye, and also new findings concerning the light distribution in the image in the intact human eye are discussed. An introduction is given to the Fourier approach to the analysis of the performance of the eye and visual system.

1964  SCHADE, O.H., S.R.  MODERN IMAGE EVALUATION AND TELEVISION (THE INFLUENCE OF ELECTRONIC TELEVISION ON THE METHODS OF IMAGE EVALUATION)

Introduces image measurement problems brought up by the development of commercial television. The solution to television problems has required growth and cooperation of optical, photographic, and electronic sciences. Present methods of analysis and the importance of the aperture response, sine-wave response, and the noise theory are pointed out. Presents data on the frequency band pass of the eye.

1965  CAMPBELL, F.W.  VISUAL ACUITY VIA LINEAR ANALYSIS

Fourier techniques are applied to the entire human visual system in analyses of the functions of the optics, the retina, and the brain. Prediction of contrast sensitivity using these analyses is satisfactory. Present contrast sensitivity functions for square and sine-wave functions, and considers binocular vision and monocular resolution. Binocular acuity is superior by approximately \( \sqrt{2} \). Further testing of this hypothesis awaits the location of a three-eyed subject who should show 3 improvement over monocular viewing!

1965  CAMPBELL, F.W.  OPTICAL AND RETINAL FACTORS AFFECTING VISUAL RESOLUTION
Green, D.C. VISUAL RESOLUTION

1. With a neum-hallul laser as a light source, interference fringes were produced on the retina directly, thus by-passing the effects of the optics of the eye.
2. Threshold contrasts for resolution of these interference fringes were measured. It was found that the contrast sensitivity decreased roughly exponentially with increase in spatial frequency.
3. The contrast sensitivity of the over-all visual system was measured with similar sinusoidal gratings displayed on an oscilloscope. At all spatial frequencies the contrast sensitivity was found to be lower than that obtained with the interference fringes.
4. By finding the ratio between the contrast sensitivities measured by these two techniques, the contrast reduction due to the optics of the eye was calculated. The effects of changes in pupil size and focus on the quality of the retinal image were determined. For an eye with a 2 mm diameter pupil the measured optical attenuation agrees with that predicted for a diffraction-limited system. With increasing pupil size the performance of the optics deviates progressively from a perfect optical system.
5. These results established that the quality of the optics is substantially better than that determined by recent ophthalmoscopic methods.

1965  FRY, C.A.  PHYSIOLOGICAL IRRADIATION ACROSS THE RETINA

This latter presents a mathematical consideration of absolute threshold data for geometrical targets of various sizes in consideration of photo receptor properties and retinal inhomogeneities.
1965

FRY, G.A.

DISTRIBUTION OF FOCUSED AND STRAY LIGHT ON THE RETINA PRODUCED BY A POINT SOURCE


This latter considers the distribution of light on the retina from a point source. The work extends the findings of other authors by incorporating the Fraunhofer diffraction pattern.

1965

WESTREIMER, G.

APPLICATION OF FOURIER METHODS TO THE HUMAN VISUAL SYSTEM


This paper examines the relation between the point spread function of the space domain and the modulation transfer function in the spatial frequency domain to understand the foundation of human spatial visual resolution. The transmission of sinusoidal object distributions into line distributions is discussed, including the demodulation of incoherent imagery depending on wavelength, optical system aperture, aberrations and defocusing. By introduction of fringe patterns on the retina, the effects of spatial frequency limitations are demonstrated for coherent illumination.

1966

CAMPBELL, F.W.

OPTICAL QUALITY OF THE HUMAN EYE

Gibbsch, B.W.


1. Optical quality of the eye was measured at eight pupil sizes between 1.5 and 6.6 mm diameter by recording the faint light emerging from the eye; this light was reflected from the bright image of a thin line on the fundus.
2. The nature of the fundus reflection was examined; it was found that the fundus acts very much like a perfect diffuser while retaining polarization.
3. Using the result that the fundus acts like a diffuser, the recorded line images were Fourier analysed to provide modulation transfer functions. These functions indicate an optical quality considerably higher than that found in previous physical studies.
4. Line-spread profiles were then derived from the modulation transfer functions. These profiles are 40% narrower than those of previous physical studies for a 3.0 mm pupil. The narrowest profile occurred with a 2.4 mm pupil.
5. Our results demonstrate that physical and psychophysical studies can yield similar estimates of optical quality. The influence of optical factors not common to both techniques is discussed. Evidence for the existence of neural "image sharpening" mechanisms is reviewed.

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Experiments in which the line spread functions of the human eye were determined for white light, monochromatic light, and with various pupil configurations are described. With large pupils, the optics of the eye are significantly poorer than a diffraction-limited system. The results indicate that neither chromatic nor simple spherical aberration limit the performance of the eye. It is concluded that the irregular variation in dioptric power over the plane of the pupil is the chief limiting factor. Another set of experiments is described in which the changes in fundus reflectivity due to photobleaching were studied. The principal experimental variable was the entry or exit point of the measuring beam in the pupil plane. A direct correspondence between changes in reflectivity and the psychophysical Stiles-Crawford effect was found. These results may be interpreted qualitatively as supporting the wave guide or antenna theory of the Stiles-Crawford effect. However, it is shown that no simple theory of retinal reflectivity can account for the data quantitatively.

A new method for the assessment of quantum fluctuation in single photoreceptor systems has been proposed. It follows principles similar to those employed in the evaluation of noise from temperature-limited devices in electronic systems; that is, it postulates that fluctuation in visual systems is a function of (1), the number of available quanta and (2) the frequency response characteristics of the photoreceptor. It is shown that attention has been directed entirely to single photoreceptor systems. However, extension of this method to systems employing multiple photoreceptors is not difficult.

Measurements of the threshold of the human eye for periodical grids and of the modulation transfer function (MTF) of the optical part of the eye have been carried out. The MTF was determined from the light being reflected from the retina. The thresholds for grids as a function of spatial frequency were determined under variation of several parameters such as length and number of grid lines, back-ground luminosity and presentation time. By taking into consideration the MTF, the influence of the optical part of the visual pathway on the threshold could be eliminated. For unrestricted presentation times, the results show strong and nonlinear influences of the neural interactions of the threshold, especially the well known increase of threshold with very small spatial frequencies. For short exposure times, the neural interactions decrease and apparently disappear at presentation times shorter than ca. 10 ms. At these exposure times, the threshold data can be explained alone from the MTF of the optical part of the eye.

The contrast sensitivity of the visual system has been determined with variable-transmittance sinusoidal test objects, by measuring the modulation-threshold as a function of spatial frequency, for monochromatic light of constant average luminance. Data were obtained for wavelengths of 450, 520, and 550 nm. There is little difference in the modulation threshold curves for red, green and blue at photopic luminances. All three have a minimum at a best-transferred frequency, $f_0$, in the photopic luminance range. When the average luminance decreases, $f_0$ decreases for all wavelengths, until, for scotopic luminance levels, contrast sensitivity increases continuously with spatial frequency.

The disagreement between physical and psychophysical estimates of human optical performance is discussed. Recent measurements of the eye's modulation transfer functions in white light for several pupil sizes are used to compare the eye with an ideal optical system in terms of normalized modulation transfer functions, point image profiles, and Strehl ratios. Several simple fundus-image profiles are derived from the measured modulation transfer functions, and the importance of these profiles to psychophysical measurements is discussed. Glare is considered as the extension of point spread functions to large angles; experimental measurements are compared with theories for the special case of angular target.

The threshold data can be explained alone from the MTF of the optical part of the eye.
It is now well established that, for many test targets, vertical and horizontal orientations yield higher visual acuities than oblique orientations. In order to assess the role of the optic of the eye in this effect, focusing errors of the eye were bypassed by using as the measure of resolving capacity the modulation sensitivity for sinusoidal interference fringes formed on the retina. The modulation sensitivity for vertical and horizontal orientation of the fringes was greater than for oblique orientations for a wide range of spatial frequencies. A similar orientation preference was found for the cut-off spatial frequencies. Measurements of the modulation sensitivity at 15° orientation intervals indicated that maxima in sensitivity were spaced at 90° intervals. Since the effects of the optic of the eye have been eliminated, the origin of meridional variations in acuity must lie in the retina and/or higher visual pathways.

1967 VAN KERS, F.L.
SPATIAL MODULATION TRANSFER IN THE HUMAN EYE
The contrast sensitivity of the human eye for sinusoidal illuminance changes was measured as a function of spatial frequency, for monochromatic light with wavelengths of 450, 525, and 650 nm. At each wavelength, data were obtained for a number of illuminance levels. All observations were taken at equal accommodation, and corrected for chromatic aberration. If the wavelength-dependent effects of diffraction on the modulation transfer are taken into account, no difference is found between the photopic contrast-sensitivity functions for red, green or blue. For mean retinal illuminances B, smaller than 300 td, threshold modulation M at a given frequency is found to increase in proportion to B,-1/2 (de Vries-Rose law). For B, greater than 300 td M remains a constant fraction of it (Weber-Fechner law). After separation of the optical modulation transfer of the eye media from the measured neural and a light-diffusion transfer function, the latter can be compared with the analytic transfer function of photographic film.

1968 CAMPBELL, F.W.
THE HUMAN EYE AS AN OPTICAL FILTER
The properties of the image-forming elements of the human eye are compared with the properties of the retina-brain system by considering them as two linear optical filters in cascade. The contrast sensitivity of the complete system is measured at a number of spatial frequency on an oscilloscope. Similar gratings are generated directly on the retina by means of Thomas Young interference, using a neone-helium laser as a coherent light source. In this manner the effect of the eye's dioptrics are bypassed. The quality of the image formed on the retina may then be determined from these two sets of measurements. The effect of pupil size on the quality of the retinal image is described to illustrate an application of the technique.

1968 GREEN, D.C.
THE CONTRAST SENSITIVITY OF THE COLOR MECHANISMS OF THE HUMAN EYE
1. To isolate the color receptive systems of the eye, a sinusoidal grating of one color was superimposed on a bright background of another color and the threshold contrast for resolving the grating was determined.
2. A procedure is described which allows one to estimate the extent by which the bright background reduces the contrast of the test grating of another color. Using this procedure, the measured threshold contrasts of the test grating were replotted in terms of the effective contrast sensitivity for the composite target.
3. The effectiveness of a red background in reducing the contrast of a green grating was found to be determined not by its apparent brightness but rather by the extent to which it excited the green mechanism.
4. The effective contrast sensitivities for a green grating on a green background, for a green grating on a red background, and for a red grating on a green background were found to be not significantly different.
5. Visual acuity for a blue grating on a yellow background was reduced from normal by about a factor of six. This loss in visual acuity was due to both a reduction in contrast sensitivity and a reduction in resolution.
V. DARK ADAPTATION

1938 HECHT, S.
SCHLAER, H.

- AN ADAPTOMETER FOR MEASURING HUMAN DARK ADAPTATION -


The original Hecht-Schlaer adaptometer is described. The parameters involved in dark-adaptation are: intensity and duration of preadaptation light; the area, retinal location, color and duration of the measuring light. All these are incorporated in the apparatus.

1949 HEFFT, V.

- REVIEW OF MARTINE STUDIES OF DARK ADAPTATION, NIGHT VISION TESTS AND RELATED TOPICS -


Contains a useful historical account, evaluation and procedure of using night vision selection tests and dark adaptation tests up to August 1946. Abstracts of 106 papers in the field, published between 1941 and 1946 are also included.

1951 CLARK, B.

- NIGHT VISION TRAINING: A SUMMARY OF RESEARCH AND PRACTICE -

31 Refs. From, "Blackwell, H., Minutes and Proc. of the HRC-Armed Forces Comm. on Vision, 29th Meeting, 1951".

Contents include: basic anatomy and physiology of rod vision, factors involved in the development and maintenance of dark adaptation; limitations of vision at night; recommended techniques for optimum seeing at scotopic intensities; physical factors affecting visibility, special problems in visual perception which occur during scotopic intensities, description and evaluation of near vision training methods.

1951 MURLEE, C.G.

- SOME FACTORS IN HUMAN VISUAL DISCRIMINATION -

30 Refs. From, "Blackwell, H., Minutes and Proc. of the HRC-Armed Forces Committee on Vision, 29th Meeting, 1951".

Includes comprehensive survey on all the accepted data up to 1951, a description of the Radium Plaque Adaptometer and the use of binoculars in night vision.

1952 CHERN. F.A.

- RETINAL ADAPTATION IN NIGHT FLYING -


1953 CHAMPANIS, A.

- AN EVALUATION OF PROBLEMS OF CHART READING UNDER RED ILLUMINATION -


Preliminary report into the problem, e.g. depth of dark adaptation required, intensities of red light, etc. Useful bibliography.

1953 PARKINSON, D.

- A COMPARISON OF SPECIFICATIONS FOR DARK ADAPTATION -


Current specifications for red goggles, red compartment lighting fixtures and red panel illumination for dark adaptation purposes are discussed and evaluated.

1953 MCLAUGHLIN, B.C.

- THE EFFECT OF RED LIGHT ON THE ABSOLUTE VISUAL THRESHOLD -


An hypothesis is advanced to account for the appearance or not of red light photosensitization in closely similar experimental situations in terms of the psychophysical method of threshold determination which is employed. This hypothesis explains the appearance in the literature on vision of conflicting data. Results are presented to support the hypothesis and to nullify the "photosensitization phenomenon".

1953 Hwang, T.F.

- THE INFLUENCE OF PROLONGED STAY IN THE DARK ON FOVEAL DARK ADAPTIVITY -


Two subjects were dark adapted for periods from 2 minutes to 10 hours. After 5 to 7 hours, foveal dark adaptivity became two times as high as after one hour. Maximum adaptivity was shown after 8 to 10 hours. The possible mechanism is discussed.
1957 FOWLS, G, BLOUNT, P.L. DAVIES, R.J.
STUDIES OF A SCOTOPIC SENSITIVITY TEST

Further experiments with a new test of night vision sensitivity are
discussed, which had already indicated: the sensitivity in the
visual field must be sampled in two dimensions, size and brightness
of the test areas can be used interchangeably.

1960 FOWLES, G.
STUDIES OF A SCOTOPIC SENSITIVITY TEST

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discussed, which had already indicated: the sensitivity in the
visual field must be sampled in two dimensions, size and brightness
of the test areas can be used interchangeably.

1960 DOBNEY, B.G.
THRESHOLD AND RATE OF DARK ADAPTATION AS
FUNCTIONS OF AGE AND TIME

Two hundred and forty subjects were used, their age range being
19-89 years. It was concluded that the threshold of dark adaptation
as a function of time was lawfully related to chronological age by
a curvilinear function. The findings are consistent with the hypo-
thesis that dark adaptation threshold and rate of dark adaptation
depend on the basic underlying physiological processes that change
with age.

1960 LEHTA, S.W.
VISUAL ACUITY UNDER RED VERSUS WHITE
ILLUMINATION

The central acuity of 3 subjects was measured at 3 photopic levels
(11, 12, and 0.34 ft.-L) of red and white light using a multiple
checkerboard acuity tester. The red light was produced by the Navy
standard red filter. The acuity was comparable under both conditions,
showing a small, negligible decrease under red light.

1960 McFARLANE, R.A.
DARK ADAPTATION AS A FUNCTION OF AGE 1.

The range of individual differences in the dark adaptation process
as a function of age is considerably greater than has previously
been supposed. Two hundred and forty male subjects, ages 16-89 were
used. Age and dark adaptation thresholds were highly intercorrelated.
The correlation improves as the time in the dark increases. The cone
and rod thresholds are highly correlated.

1961 DOBNEY, B.G.
THRESHOLD AND RATE OF DARK ADAPTATION AS
FUNCTIONS OF AGE AND TIME

Measuring dark adaptation near the asymptote of the function requires
30-40 minutes. When it is required to screen large numbers of people,
a test of this length is impracticable. Thus a short test of dark
adaptation, predictive of thresholds near the asymptote was developed.
The dark adaptation for 241 male subjects, ages 16-89 years was
measured. A multiple correlation of 0.91 was obtained between the
threshold sensitivity at the 40th minute (the criterion), and age
combined with dark adaptation thresholds taken at intervals of 1
minute for the first ten minutes. A correlation of this magnitude
allows application of the regression equation to individual performance
for the accurate prediction of terminal levels of dark adaptation
sensitivity. It was concluded that 3 minutes of pseudoadaptation plus
ten minutes of measurement at intervals of one minute under standard
laboratory conditions as described permit accurate prediction of
terminal levels of dark adaptation sensitivity.

1962 KINNEY, J.S.
A REVIEW OF RECENT LITERATURE ON NIGHT VISION
TESTING
24 Refs. Armed Forces-NRC Comm. on Vision, Visual Problems of the

Only two new tests have appeared since Berry's review (see this
section under Berry, 1949), both of which rest on firmer experimental
facts than their predecessors. These are the Medical Research
Laboratory Test (MRL) and the Army Night Vision Tester. One variable
that affects long-term stability is exposure to sunlight, hence
seasonal variations are large. The validity of testing is examined
from three points of view: is the test measuring what it is supposed
to, can night vision testing be used to predict performance in a
field situation, and the relationships among a range of night vision
tasks from simple to complex.

1962 McFARLANE, R.A.
DARK ADAPTATION AS A FUNCTION OF AGE 2.

Biochemical regeneration rate of rhodopsin might be altered if
retinal blood or tissue temperature are raised by hyperthermia
in super- or hypersonic aircraft flight. Peripheral dark adaptation
curves were obtained in 3 subjects at comfort (72.0° C) and 85.6° C
temperatures alternately, using a modified Hecht-Schlaer adaptometer.
In 24 heat experiments, the subjects were exposed to 85.6° C ambient
air temperature for 35 minutes after which the heat was shut off.
The chamber temperature declined, but the subject's remained in
relatively constant hyperthermic conditions during the subsequent
35 minutes of dark adaptation tests. The curves obtained differed
from the controls, indicating an increase in dark adaptation rate
under the imposed thermal stress conditions.

1966 KENT, P.R. OXYGEN BREATHING EFFECTS UPON NIGHT VISION
THRESHOLDS

Rod and cone night vision thresholds were measured while breathing
oxygen at 1 at. for periods up to 140 minutes and at 2.82 at. for
20 minutes. The measurements were taken on the Stett-Schloer adapt-
ometer. One of the 5 subjects showed elevated thresholds at 1 at.
and 2 or the remaining 4 at 2.82 at. Both rod and cone thresholds
were lower after fasting subjects ingested 100 grams of glucose
while breathing oxygen at 1 at.

Also see abstract under Atmospheric Effects.

1967 ADVISORY GROUP FOR AEROSPACE RESEARCH AND
DEVELOPMENT AIRCRAFT INSTRUMENT AND COCKPIT LIGHTING BY
RED AND WHITE LIGHT

It was concluded that scanning an instrument panel using a dim white
light causes only a slight loss of dark adaptation compared to that
which is possible to achieve after looking at equally legible red
lit instruments. There is little difference in the level of adaptation
associated with either low temperature white or lunar white
lit instruments. At an experimental level it is considered the
disadvantages of red integral lighting (loss of color coding,
accommodation difficulties) outweigh the advantages (slightly lower
threshold). Floodlighting should be easily interchangeable from red
to white, white being used unless the visual task requires the evader
to detect external objects, when it should be red. If map-reading
is required, the only illumination of the map should be white,
the rest being red to maintain dark adaptation on the peripheral retina.
Integral and floodlighting systems should be variable in intensity.

1968 WHITCOMB, M.A. NEAR VISUAL ACUITY UNDER LOW LEVEL RED AND
WHITE LIGHT

The near visual acuity of 17 subjects ages 35-45 years was measured
under white light and red light of 0.1 ft-Luminescence level. Near
visual acuity was significantly better under white light for acuity
demands of 20/30, 20/40 and 20/50. Visual acuity is equally good
under red or white light when the acuity demand is 20/70 or larger
and the visual acuity is equally poor under red or white when the
acuity demand is 20/20.

1969 WHITZMAN, D.O. EFFECT ON VISION OF REPEATED EXPOSURE TO CO2
Kinney, J.S. Lurie, S.N.

The visual effects of repeated exposure to CO2 at levels commonly
regarded as innocuous were investigated. The exposure varied
cyclically from 0.03% (air) to 3.0% at one atmospheric pressure
every 24 hours for 6 days. It was found that night vision sensitivity
was repeatedly impaired during the period of exposure.

Also see abstract under Atmospheric Effects.

VI. DEPTH PERCEPTION AND STEREOPSIS

1908 James, G.T.B. ON THE MEASUREMENT OF THE STEREOSCOPIC VISUAL ACGUITY

5 Refs. Lancet, 1:1763, 1908.

An apparatus was devised on which the Howard-Dolman apparatus was later based. The principle of the apparatus was to exclude all monocular clues, including relative size. Sticks of different sizes were therefore chosen so that when viewed through an aperture at 20 feet, even though they are at different distances behind the aperture they subtend the same visual angle. Mention is also made of a stereoscope for near based on the same principle.

1918 U.S. WAR DEPARTMENT AIR SERVICE MEDICAL


The report states repeatedly that plane landing requires perfect stereovision.

Also see abstract under Atmospheric Effects.

1919 Spearman, C. DISCUSSION ON VISUAL REQUIREMENTS OF AVIATORS: PART III


The landing aviator does not use stereopsis to determine how far off the ground is, but only the shape of the ground and speed of approach. Hence stereoscopic vision is only of secondary importance in judging distance; it is useful for judging relative distance but not absolute.

1919 Howard, H.J. A TEST FOR THE JUDGEMENT OF DISTANCE


The development of the apparatus was prompted by the aviation standards (1919) in which a hand stereoscope is used, an instrument allowing no quantitative analysis. The apparatus is based on James' apparatus, (1908-see this section above), as it eliminates all cues except binocular parallax and retinal image size. One hundred and six subjects were employed and tables showing their age, occupation, vision, muscle balance, NO accommodation, NO convergence, pupillary distance, and binocular parallactic angle are given. They show a high correlation between small parallactic angle and high quality visual parameters. The best performers had either ortho- or eso-muscle balances, none had exo. The limit between "normal" and "abnormal" standards of distance judgment is thought to be 8.0 seconds of arc. This represents approximately 24 2/3 mm for p.d. equals 57 mm to 19 1/2 mm for 72.5 mm p.d. The test is done with a shutter as most judgements are done instantaneously.

1931 Herson, C. PRESENT OPHTHALMOLOGICAL STANDARDS FOR COMMERCIAL AVIATION IN THE UNITED STATES


The report discusses the visual standards for commercial aviation (1931). Certain parts of the ocular examination are clarified and the military and commercial aviation requirements are compared. P. 1. By. "Binocular parallaxic displacement plays little part at the great distances at which judgment must be made in flying."


P. 3. Discussion on whether a man should be disqualified on a failed depth perception test alone.

1932 Jablonski, B.B. MONOCULAR VISION AND OTHER PECULIAR PHASES OF FLYING AS REGARD DEPTH PERCEPTION


Depth perception is very important in taking off and landing a plane, especially the latter. To date there were no accidents in which one-eyed pilots were found at fault. A flyer who learns to fly with one eye and has never experienced binocular vision in flying, always depends on monocular clues for depth perception and doesn't contend with the loss of something he has never had during flying. Monocular pilots are often good pilots in spite of their defects and sometimes perform better than those without handicaps. However, since there is adequate and often excessive pilot material available, there is no need to certify any handicapped applicant who must depend on one eye.

1933 Topnovski, W.J. SUGGESTED MODIFICATION OF THE DEPTH PERCEPTION APPARATUS


A device is placed over the depth perception apparatus (e.g., the Howard Dolman Box) like a roof, painted black and containing four 25 watt frosted light-bulbs. A small steel bracket screwed at the four corners of the depth perception apparatus prevents the top from slipping and keeps it stationary. This added device is believed to improve the depth perception apparatus by removing shadows and eliminating glare, and preventing applicant from looking over the top which otherwise aids the higher score with the test. The author offers no statistical evidence of improved performance in
depth perception testing using his modification device; or whether or not it is a common accepted modification.

1940  
U.S. ARMY TECHNICAL NOTES ON EYE, EAR, NOSE AND THROAT IN AVIATION MEDICINE  

The actual manual was not seen. The following is abstracted from "McFarland, Ross A., Human Factors in Air Transportation, McGraw-Hill Book Co. Inc., 1st Ed., 1953." Older pilots have learned to use secondary cues. It has been found that a new candidate making an average error greater than 30mc can improve his score by repeated trials, provided he has no ocular defect.

1942  
VERHOEFF, F.H.  
SIMPLE QUANTITATIVE TEST FOR ACUITY AND RELIABILITY OF BINOCULAR STEREOPSIS  

The Verhoeff stereoscopic test is explained. The greatest distance is found for which all 8 presentations are correct; the acuity is then deduced as follows -

$$\text{acuity} = \frac{\text{distance}}{100} \quad (\text{distance \ in \ cm})$$

It is claimed that this test is far superior to the Howard-Dolman test, one of the advantages being that it reduces guessing to a minimum. The two tests are compared at length. In the discussion following the paper, Aseher comments, "Accommodation and convergence... are of no help whatever at the distance important for flying."

1946  
KIRSCHNER, L.E.R.  
DEPTH PERCEPTION AND FLYING ABILITY  

The paper is a summary of results of studies relating ocular muscle balance to depth perception in the RCAF. An excellent survey of the literature is included. The apparatus employed to evaluate stereopsis is a wooden version of Verhoeff's 1942 model reproduced three times larger than the original. The results of the experiments show:

1. Good visual acuity is an important factor in depth perception.
2. Fusion amplitudes and depth perception are independent.
3. There was no relationship between depth perception and heterophorias in 303 subjects.
4. Orthophoria bears no relationship to flying ability.

1950  
NICHOLS, J.P.V.  
THE RELATIONSHIP OF HETEROPHORIA TO DEPTH PERCEPTION IN AVIATION  
Includes a most extensive review of the subject.  
Also see abstract under Visual Standards.

1950  
RIPLEY, P.H.  
ANTISTEREOSCOPIA IN AIR FORCE CABINETS AND ITS RELATIONSHIP TO THE HOWARD-DOLMAN DEPTH PERCEPTION TEST  
No relationship was found.

1951  
KINSLEY, C.C.  
SOME FACTORS IN HUMAN VISUAL DISCRIMINATION  
30 Refs. From "Blackwell, H., Minutes and Procs. NRC-Armed Forces Committee on Vision, 25th Meeting, 1951."

The paper includes a brief survey of the generally accepted data concerned with stereoscopic acuity and the discrimination of real depth.  
Also see abstract under Dark Adaptation.
1953 ALTMAN, A.

ANISEKOSIS AND THE HOWARD-DOLMAN TEST


Experiments with 2 subjects showed that aniseikonia in the horizontal meridian produced a constant error of the same direction and magnitude in the setting of the movable rod as the aniseikonia. The errors in the Howard-Dolman test were only 1/3 to 1/2 of that predicted from binocular disparity. The mean variation about the average position varied from day to day.

1957 CHASTAIN, D.J.

SURFACE TEXTURE AND DEPTH PERCEPTION

Ciba, P.A.


Experiments on the role of irregular texture for depth perception were made using a plate stereometer to measure true and apparent differences as well as an effect of illumination on spatial localization. The results were obtained using two groups of ten subjects and indicated that the accuracy of spatial localization of plane-parallel visual surfaces depends on the perception of separate textural elements, i.e., grain size, grain density, and distribution and distinctness of reference points within the surface pattern. Surfaces with coarse and distinct grain seen at bright illumination provided the greatest accuracy of spatial discrimination, but even microstructure of surface texture improved depth perception when grain density, grain size and conditions under which it is observed furnished transverse disparity and stereoscopic cues.

1958 MILLER, E.P.

EVALUATION OF CERTAIN VISUAL AND RELATED TESTS: V. RETINAL RIVALRY


Retinal rivalry as a possible additional screening device is without value. One hundred and twelve naval aviation cadets were examined and it was found the alternation rates bore no relation to their stereoscopic thresholds.

1967 ADAMS, A.J.

STEREOSCOPIC DEPTH ASSOCIATED WITH CYCLOTORSIONAL EYE MOVEMENTS


The conditions under which cyclotorsional eye movements occur is outlined. It is shown how they may influence depth perception and produce depth illusions. An explanation is given for the recently reported traffic signal illusion (Bugalski).

1968 Whitcomb, M.A.

THE MEASUREMENT OF VISUAL FUNCTION (SYMPOSIUM)

PROCEDINGS OF SPRINGS MEETING 1965


The report includes a section on distance vision including stereopsis. One paper consists of a brief review of the instruments to measure stereopsis, another is concerned with the distinction between perceived depth and distance. Also see abstract under Color Vision, Dark Adaptation, Ocular Munula Balance, Re refractive Error and Refraction, and Visual Acuity Static.

1968 LUBIN, S.M.

RELATIONSHIP BETWEEN STATIC AND DYNAMIC STEREOSCOPY


Equidistance settings were obtained from 50 subjects with a Howard-Dolman type apparatus which was either stationary or rotating about the subject at angular speeds of 60-180°/second. Correlations between settings decreased as the disparity of the speed was compared increased and there was a sharp drop in correlation between the stationary position and any speed. At any given speed of rotation, there was an increase in variability of settings as the viewing time decreased, and a sharp increase below 0.3 seconds. A positive localization error was made by 740 subjects and a negative error by 260. There appears to be a relationship between positive errors and epiphoria and negative errors and anepiphoria.

1968 Ohlbaum, M.E.

THE EFFECTS OF ALTITUDE ON CERTAIN ASPECTS OF VISUAL PERCEPTION


Some loss of accommodation, convergence and stereopsis was found at altitudes up to 18,000 feet, and quantified against hypoxia. Wilson's theory of reduced ciliary tony was apparently negated insomuch as a slight increase in tony was found. No plus acceptance at near was found despite large decrements in accommodation. Thus no justification for the present USAF standards of minimum accommodation was found and an absolute minimum of any 4-5 D is suggested. The author agrees with Scobee in that altitude has no significant effect on the epiphoria.
1969 MULLER, H.D. RESEARCH ON VISUAL PROBLEMS OF SPACE FLIGHT et al.


The work covers the investigation of the optical parameters of the Apollo pressure suit helmets and visors, and the effect of optical distortions upon visual performance. The primary visual function investigated is binocular depth perception. Work was also carried out on photokeratitis due to exposure to U-V radiation and the effect of the visual transmittance of the gold-coated lexan visor on color perception. The apparatus used in the binocular vision depth measurements includes:

1. The Leaf Room
2. Howard-Delaney Peg Test
3. Space Eikometer
4. Tilting Plane Eikometer
5. Tilting Lunar Surface Model

1969 LURIA, S.H. THE RELATION OF "DUCTION" TO DYNAMIC STEREOSCOPY

Kent, F.H.


The relation between duction break-recovery (B/R) ratios and localization error in a test of dynamic stereoscopy was examined in 73 young men. Positive (near) localization errors, exophoria, high negative spherical correction, high adductory and low abductory B/R ratios were found to be related. Positive errors were associated with high adductory and low abductory B/R midpoints for exophoria but the relationship for exophoria was not clear. The difference between the adductory and abductory B/R ratios increased with increasing positive error. Differences between the adductory and abductory B/R midpoints were greater for exophoria than exophoria and increased with increasing positive errors. The magnitude of the error was related to the magnitude of the spherical correction which the subject wore during the experiment. The direction and magnitude of localization error was not much more predictable from duction measurements than from phorias.

1951 HAMBLEY, P.R. DISPLAYS OF VISUAL PROBLEMS OF PILOT IN PRONE POSITION

Hobbs, R.W.


The test personnel were subjected to an elevated gate while in a prone position in bed. A determination was made of the muscle balance and ability to maintain the elevated gate. Elevation of 15-30° gave all subjects discomfort.

1960 HOPKINS, C.G. DISPLAY AND CONTROL REQUIREMENTS FOR MAHNNED SPACE FLIGHT

Hauerscheidt, D.E.

Anderson, M.J.


A study was made of the display and control requirements for a manned orbital vehicle of the "space-ferry" type. The mission includes launch, rendezvous, re-entry and landing. Displays, controls and control panels were designed to meet these requirements. Representations of these were constructed and incorporated into full-scale mockups of cockpits for 2 alternate display and control systems.

1961 ADAMS, O.S. HUMAN PERFORMANCE AS A FUNCTION OF THE WORK-REST RATIO DURING PROLONGED CONTINENT

Chilas, W.D.


Many subjects were confined for up to 15 days while they undertook 5 performance tasks including one to detect warning lights and one pattern discrimination test. It was concluded that with proper control of selection and motivational factors, crews can work effectively for periods of at least two weeks and possibly longer using a 4-on and 2-off work-rest schedule.

1961 BENDERHAGEN, T.P. A STUDY OF VISUAL SIMULATION TECHNIQUES FOR ASTROMONIAL FLIGHT TRAINING

Wolpin, M.P.


A study of the engineering requirements for visual simulation in astronaut flight training, and the present techniques used to accomplish the simulation was carried out. The report includes how and why the techniques were developed to optimize the training value of a simulator.
1962 JONES, E.R. 
Hamm, W.H. 
VISION AND THE MERCURY CAPSULE 
The paper contains predictions of what might be seen and how through 
the window of the Mercury capsule. This was written, of course, 
before the first Mercury mission had taken place. Also contained 
in the paper are pictures of the instrument panels, the window, 
and refraction through the latter, etc.

1962 MILLER, J.W. (Ed.) 
VISUAL PROBLEMS OF SPACE FLIGHT 
Extensive Refs. Nat. Acad. of Sciences-Nat. Res. Council, 
Pages 20-24: Discussion of visual displays with consideration for 
the various novel problems of space flight, e.g. absence of gravity 
and the presence of various accelerative forces.

1962 McNELLY, C.F. 
SIMULATION TECHNIQUES FOR SPACECREW TRAINING: 
STATE OF ART REVIEW 
Simulation technology is discussed, and the present programs for the 
development of new techniques for spacecrew training are presented. 
The requirements are given for visual simulation in a simulator, 
especially those which demonstrate extravehicular views that would 
have to be observed by the astronaut.

1963 BIRKENHAGEN, T.P. 
Johnson, A.E. 
Stephan, S.C. 
Wolpin, M.F. 
DEVELOPMENT OF VISUAL SIMULATION TECHNIQUES 
FOR ASTRONAUTICAL FLIGHT TRAINING 
This paper considers the uses of high resolution television and an 
electronic planetarium as visual simulators.

1964 CAIMER, C.A. 
PILOT EYE FIXATIONS WHILE FLYING SELECTED 
MANEUVERS USING TWO INSTRUMENT PANELS 
The first panel configuration had vertically moving tape, the second 
a round dial. Sixteen subjects were tested in a NB-5 Simulator 
with flight characteristics of a high performance jet aircraft. 
Standardised flight profiles were employed. The data collected 
allows analysis of performance, eye movements and a correlation 
of performance and eye movements for each combination of maneuvers 
and instrument panels. There was no clear-cut distinction between 
use of reading vertical or circular instruments, a vertical instrument 
being preferred for some measurements and a circular for others. It 
appears that the vertical panels gave more feedback from supporting 
instruments through peripheral vision.

1965 CLARK, W.C. 
KAMMER, J.W. 
PILGRIM, H.P. 
THE PILOT'S VISUAL TASK: A STUDY OF VISUAL 
DISPLAY REQUIREMENTS 
16 Refs. 96 pp. Chap. VII. Simulation Display Systems (pp.77-84), 
Interesting chapter on computer-simulated space flight, both from 
the spectator and the astronauts point of view.

1968 VALVERDE, H.H. 
FLIGHT SIMULATORS: A REVIEW OF THE RESEARCH 
AND DEVELOPMENT 
General review of flight simulators (research and development) since 
1949. The report does not include mathematical models and space 
flight simulators.
1966 HOLLAND, C.L.  
PERFORMANCE AND PHYSIOLOGICAL EFFECTS OF LONG-TERM VIBRATION


The investigation was of human performance as a function of selected parameters of simulated, random, vertical vibration environments. Twelve subjects were subjected to 4 different vertical vibration environments for 6 hours at a session. The subjects had to perform 2-dimensional, compensatory tracking and secondary visual and auditory loading tasks. The visual task consisted of reactions to red and green warning lights. It was found that the subjects reacted quicker to lights than controls when 2 cpa = power peak but slower when 5 cpa = power peak.

1968 SHERFISERER, R.M.  
INVESTIGATION OF THE EFFECTS OF VIBRATION ON DIAL READING PERFORMANCE WITH A NASA PROTOTYPE APOLLO BALANCE


Sinusoidal vibration was used and the force of gravity was passed through the X-axis of the body (subject lying down) with vibration in the X-axis in one experiment, and in the Y-axis in another. Dial-reading ability was assessed at 6, 11, and 15 Hz with the helmet, with and without a liner. The vibration intensity varied ±2.2 G in the X-axis experiment, and ±0.96 G in the Y-axis experiment.

The results showed that along the X-axis, dial-reading performance deteriorated most at 11 Hz., less so at 15 Hz. and even less at 6 Hz. Along the Y-axis, the dial-reading performance tended to increase with increasing Hz., but it was better with a liner at 6 Hz. and without a liner at 15 Hz.

1968 RUBENSTEIN, L.  
SOME EFFECTS OF X-AXIS VIBRATION ON VISUAL ACUITY


Four experiments were conducted to measure vernier visual acuity during sinusoidal vibration of the head in the X-axis (side-to-side). In one half of each experiment, peak acceleration amplitude was held constant at one G, in the other half displacement amplitude was held constant at 0.03 cm. Frequency was the main independent variable.
IX. FLASH BLINDNESS, GLARE AND RADIATION EFFECTS

1923 BRITISH JOURNAL OF OPHTHALMOLOGY: DISCUSSION ON OPHTHALMOLOGY IN ITS RELATION TO THE NAVY, ARMY AND AIR FORCE

This paper is an example of collective opinion influencing visual standards rather than experimental evidence. For example, "recent experience seems to show that for the pilot the most important effect of glare is to cause lack of convergence and accommodation."

Also see abstract under Ocular Muscle Balance.

1957 HAMILTON, C.E.
THE EFFECT OF A HORIZON-LINE LUMINANCE GRADIENT UPON TARGET DETECTABILITY IN ITS VICINITY

Three series of experiments were reported indicating the magnitude and spatial extent of effects of a horizon-line luminance gradient upon the detectability of nearby targets.

1st series - Targets were viewed foveally against non-uniform background fields of photopic luminances.
2nd series - Targets were viewed peripherally against non-uniform background fields of scotopic luminances.
3rd series - Targets were viewed against uniform backgrounds covering the range from photopic to scotopic luminances (providing a basis for evaluating some of the findings of the first 2 series).

The targets were always presented for 1 second. Results showed a luminance gradient of 2:1 from above to below the horizon-line raises the threshold contrast by only moderate amounts. With the target above the horizon, the target threshold contrast increased less than 1% compared with the uniform field, regardless of the position of the target with respect to the horizon-line. With the target below the horizon, threshold contrast increased by 39% when the target was just adjacent to the horizon. It decreased less than 7% when the target was removed 20 feet from the horizon-line. The horizon-line effect is reduced as the background luminance decreases, being zero for scotopic luminance levels.

1958 MITCALF, R.D.
Visual recovery times from high intensity flashes of light

Four subjects were exposed to a level of illumination comparable to that likely to be encountered during nuclear operations, and their visual recovery was recorded. Extrapolation of the results to the estimated burn threshold indicates a maximum recovery time of 170 seconds to discriminate a brightness contrast comparable to reading red-letter aircraft instruments.

1959 LEISH, I.J.
OBSERVATIONS ON MICE EXPOSED TO COSMIC RADIATION IN THE STRATOSPHERE: A LONGEVITY AND PATHOLOGICAL STUDY OF 85 MICE

No Refs. Military Medicine, 24:635-647, 1959.

See abstract under Atmospheric Effects.

1960 STEINHOLD, H.
Eye Hazards and Protection in Space

The report is concerned exclusively with the sun and retinal burns (includes photographic and subjective reports). The report gives data of solar irradiance near the various planets and explains why the critical time of exposure to the sun to produce retinal burns does not decrease appreciably as the sun is approached.

1961 ALLEN, M.J.
A STUDY OF VISUAL PERFORMANCE USING OPHTHALMIC FILTERS


A gradient density filter was found to be superior to naked vision or other filters at about 7,000 ft.- lamberts. A Link trainer instrument panel was used and atmospheric conditions were controlled.

1961 SEVERIN, S.L.
RECOVERY OF VISUAL DISCRIMINATION AFTER HIGH INTENSITY FLASHES OF LIGHT


This study attempts to evaluate the use of a Zeiss Light Coagulator as an experimental source to determine the relationship between exposure of high intensity light and visual recovery. General conclusions: the Zeiss Light Coagulator may be used as a research tool to investigate flash blindness and whether or not it can be measured. "Recovery from dazzle is consistent and reproducible within acceptable limits for biologic experimentation." Also, the recovery time increases with increasing intensity of illumination, and the functional loss of vision following a dazzle is decreased by increasing the luminance of the task to be viewed.
The study showed that the Hoyer-Schwlckerath Zeiss light coagulator can be used as a research tool to investigate flash blindness. Results indicated that daily recovery is consistent and repetitive within acceptable limits for biological experimentation. All test flashes were of 0.13 sec. duration. Two main trends in the results were found: (1) recovery time increased with increasing intensity of the test flash; (2) time of functional visual loss following dazzle decreased by increasing luminance of the task to be viewed.

The report contains a very comprehensive guide and bibliography. Sections are presented on:
1. Solar Radiation - includes sunspots, solar flares, solar electromagnetic and corpuscular radiation, flare radiation damage, and proton events.
2. The Van-Allen Belt - includes inner and outer zones, shape, composition, and biological effects.
3. Galactic Cosmic Radiation - includes properties and effects.
5. Instrumentation - includes passage of radiation through matter, and protection against various primary and secondary radiations.

The mathematical presentation of the data of the first thermal pulse was obtained in the Dominic Test Series in 1961. An analysis was made of the retinal irradiation from the first thermal pulse energy from weapon yields of 1 to 3,000 kilotons. Retinal irradiance decreases with increasing yield and fall well below the threshold burn levels for yields of 1 kiloton or greater. Since the time to minimum for 1 kiloton detonation is about 2.5 milliseconds and increases with weapon yields, it is concluded that closure of eye protective devices could only occur after this time for low altitude detonation of 1 kiloton or greater. For weapon yields of 3,000 kilotons or greater, it was concluded that damage could occur within 1.5 milliseconds.

The source used was an argon gas forced transpiration arc. Calibration techniques, monitoring instrumentation, and procedures for studying the effects of ultraviolet on the eye were presented. Rabbit eyes were used, plus some human material. Photophobia thresholds were established for various wavelengths and predictions made for keratitis thresholds for man in outer space. Electron microscopy photographs are included as evidence. Results are presented for lethality in the exposed rabbit cells. It was noted that the critical radiant exposure for photokeratitis in man will be surpassed unless protection is given. Stress is also given to the extreme accuracy required of ultraviolet transmission data of protective devices for it to have useful engineering applications.
X. FLICKER FUSION FREQUENCY

1953
BROOKS, J.
Simmons, E.
Taylor, H.L.

CHANGES IN FLICKER FUSION FREQUENCY UNDER STRESS


Within a framework of studies on changes of "fitness", the flicker fusion frequency was determined during a control period and under the following conditions:
1. Moderate visual strain
2. Strenuous visual strain
3. Nutritional stresses
4. Miscellaneous severe stresses—hard physical work, work in hot environment and lack of sleep.

The mechanism involved in depression of the fusion level when demonstrated (starvation, strenuous visual work) is not clear and probably varies. The experiment shows the decrease of fusion level cannot serve as an index of degree of involvement of the central nervous system in biologic stresses of the type applied in this study, or that this involvement is minimal.

1962
BEISCHER, D.B.
Miller, E.F.

EXPOSURE OF MAN TO LOW INTENSITY MAGNETIC FIELDS

Two subjects were exposed for 10 days to a magnetic field of 1/1000 gauss magnetic field (50 gammas). The results of a number of physiological and psychological tests were not affected, including space perception. However, decrements were observed in the visual field and especially peripheral critical flicker frequency.

1967
BEISCHER, D.B.
Miller, E.F.

EXPOSURE OF MAN TO LOW INTENSITY MAGNETIC FIELDS IN A COIL SYSTEM


Travel beyond the earth environment will mean near absence of a magnetic field. This paper is a continuation of the 1962 study by the same authors. It supports the previous study in that the scotopic flicker fusion frequency gradually decreases. This is reversed after exposure. Problems of life in a magnetic field free environment are discussed.
The occupational vision tests with the Orthorater are sufficient for the present purposes. The far and near point tests appear to be of equivalent reliability.

1945 STIFLER, A. B., GALLAGHER, J. R. 
EVALUATION OF STEREOPSIS: A COMPARISON OF THE HOWARD-DOLMAN AND THE VERHOEFF TEST
See abstract under Depth Perception and Stereopsis.

1946 KESCHNER, L. S. G. 
DEPTH PERCEPTION AND FLYING ABILITY
No relationship was found between depth perception scores, hetero-
phoria and flying ability for 303 subjects using a modified Verhoeff
instrument.
Also see abstract under Depth Perception and Stereopsis.

1947 SUCCESE, R. C. 
TESTS FOR HETEROPHORIA
Green, E. L.
The paper is concerned with the comparison of red and white Maddox
rods in the evaluation of heterophoria.
Also see abstract under Ocular Muscle Balance.

1951 MEISNER, C. C. 
SOME FACTORS IN HUMAN VISUAL DISCRIMINATION
30 Refs. From, "Blackwell, B., Minutes and Proc. of the HRC-Armed
Forces Comm. on Vision, 29th Meeting, 1951."
Much data on the Radium Plaque Adaptometer is given, together with a
discussion of the use of binoculars for night vision.
Also see abstract under Depth Perception and Stereopsis.

1956 CLOVER, H. C. 
HIGH ALTITUDE HELMET VISUAL PROBLEMS
1 Ref. Wright Air Dev. Center, Wright-Patterson AFB, Ohio. WADC
An analysis is made of the various visual problems in the design
and usage of the high altitude suit visors. The visual problems
include fields of view, optical distortions, eye relief, antifogging

1959 BIESKE, R. L. 
AUTOMATIC TEMPERATURE CONTROLLERS FOR THE
MA-1 ALTITUDE HELMET VISOR
4 Refs. 4 Appendices on Controller Specifications, Aero. Med. Lab.,
Wright-Patterson AFB, Ohio. WADC Tech. Rep. 59-232, AF 33(16)-5250,
May 1959.
The report covers the technical aspects of a contract for the
development of automatic temperature controllers for the MA-1
Altitude Helmet Visor. The controllers were designed to be mounted
inside a new high altitude helmet and to maintain the interior
surface temperature of the helmet visor by control of the power
supplied to an electrical heating coating provided in the visor.
The controller is transistorized and may be installed in helmets
already provided by the Air Force.

1960 ALLEN, M. J., CARTER, J. R. 
AN INFRA-RED OPTOMETER TO STUDY THE
ACCOMMODATIVE MECHANISM
The apparatus continuously monitors the accommodative state.

1961 ALLEN, M. J. 
A STUDY OF VISUAL PERFORMANCE USING
OPHTHALMIC FILTERS
See abstract under Flash Blindness, glare and Radiation Effects.

1961 SEVERIN, S. L. 
RECOVERY OF VISUAL DISCRIMINATION AFTER
HIGH INTENSITY FLASHERS OF LIGHT
See abstract under Flash Blindness, glare and Radiation Effects.

1965 GILLESPIE, R. W. 
COMPARATIVE EVALUATION OF USAF STANDARD
A/P220-2 AND IMPROVED A/P226-1A HIGH ALTITUDE,
FULL PRESSURE FLYING OUTFITS
4 Refs. Systems Engineering Group, Res. & Tech. Div., Wright-
This report is concerned mostly with the suit itself. However, it
contains several photos of the helmet and the complete optical
test data of the helmet for refractive and prismatic power,
transmittance and base.

1966 CARPENTER, J.A.
EVALUATION OF 21 GOLD VISOR
Richey, E.O.
Results are given of a flight evaluation to determine if the use of
a 21 gold visor in daylight degraded the performance of flight duties.
Thirteen pilots flew 17 sorties. Slightly diminished vision under
cloudy conditions was experienced by some individuals, although missions
were all satisfactorily completed. A 21 gold visor is recommended
during daylight hours for eye protection from nuclear explosions.

1967 KOOP, B.M.
RESEARCH AND DEVELOPMENT OF HELMET FACEPIECES
FOR SPACE PROTECTIVE ASSEMBLIES
The tolerances were described within which materials for facepieces
should fall. Tests were also described to evaluate the flatness,
distortion, radiation transmission, and solar irradiation of the
materials.

1968 SCHUEMERS, R.W.
INVESTIGATION OF THE EFFECTS OF VIBRATION
ON DIAL READING PERFORMANCE WITH A NASA
PROTOTYPE APOLLO HELMET
Systems Command, Wright-Patterson AFB, Ohio. AMRL-TR-67-205,
February 1968.
See abstract under Effects of Vibration.

1968 TREDICT, T.J.
SPECTACLES IN THE COCKPIT
Kinnin, E.
Twenty-eight per cent of the required medical data for pilot candidates
in the USAF is devoted to eye findings. "The visual standards for
eligibility for pilot training have changed little since their estab-
lishment. As of mid-year 1967 nearly 40% of the Air Force pilots
were of the presbyopic age"—this would seem to mean over 40 years old.
As most older aircraft use red cockpit lighting at night,
chromatic aberrations exaggerate presbyopia. Flat top bifocals
are the standard issue, but others, e.g. baseball-type, can be
supplied.

1968 DECKER, T.A.
RESEARCH LEADING TO NEW VISION TEST TECHNIQUES
FOR USE IN THE SPACE ENVIRONMENT
Faintsman, T.
90 Refs. NASA/Ames Res. Center, Moffett Field, California.
Grant No. NGR 44-012-099, October 1968.
The paper concerns the development of a space borne vision tester
for use in the NASA Apollo Applications Program. The report is
divided into the selection of visual functions to be measured, the
initial phases of new test development and the gathering of baseline
data to aid in the evaluation of new vision tests. It reviews the
special stresses of the space environment and on this basis selects
the visual parameters that should be monitored. These include: a
test of binocular coordination; a test of visual fields; a test of
retinal sensitivity; a test of intracocular pressure.

1969 CROSBY, J.K.
RESEARCH ON VISUAL PROBLEMS IN SPACE FLIGHT
et. al.
5 Refs. NASA, Manned Spacecraft Center, Houston, Texas.
See abstract under Depth Perception and Stereopsis.

1969 LALIBERT, A.J.
DESIGN, DEVELOPMENT AND PRODUCTION OF PRESSURE
SUITS SPECTACLES
No Refs. NASA Manned Spacecraft Ctr, R & D Procurement Branch,
Contract NAS 9-8090. Submitted by Univis Inc., Ommitech Division,
The author was commissioned by NASA to produce spectacles suitable to be worn in space. As well as correcting any errors, they must also:

1. Protect against both infrared and ultra-violet solar radiation.
2. Provide the widest possible field of vision.
3. Be able to withstand high gravitational forces without dislodging.

The paper describes the difficulties of undertaking such a project and contains transmission curves for the various plastic lenses and side-shields.

1970

DODGE, T.A.
Sperling, R.C.

RESEARCH LEADING TO NEW VISION TEST TECHNIQUES FOR USE IN THE SPACE ENVIRONMENT

Univ. of Texas, Graduate Sch. of Biomedical Sciences, Texas Medical Center, Houston, Texas. NASA Grant No. NLR-64-012-099, January 1970.

This paper follows that of October 1968 which dealt with the nature of the problem and the initial stages of its investigation. It is concerned with the specific procedures and instruments set out in the previous paper.

XII. ILLUSIONS AND VISUAL PERCEPTION

1. ANISEIKONIA
2. AUTOKINESIS
3. CYCLOPSIONAL EYE MOVEMENTS
4. GRAVITATIONAL AND VESTIBULAR EFFECTS
5. MYOPIA, SPACE MYOPIA AND CARISEFIELD
6. ROLE OF INSTRUCTION

1. ANISEIKONIA

1942

ELLIOT, A.J.

RELATIONSHIP OF ANISEIKONIA TO FLYING PERFORMANCE IN 75 GREEN TRAINING PILOTS AND 50 EXPERIENCED PILOTS


Aniseikonic lenses of magnification 1, 2, 3, and 4 at axes 45°, 90°, 135°, and 180° were worn in a series of flights on RCAF aircraft. Most marked effects were noticed when landing on a level grass field some distance from boundaries where no parked aircraft or other monocular clues were present. A similar situation would be smooth water away from a shore or land after a snowfall. In extreme conditions of aniseikonia, pilots tend to fly into the ground as the latter seemed farther away than it was.

1943

DARTMOUTH EYE INSTITUTE

INCIDENCE AND EFFECT OF ANISEIKONIA ON AIRCRAFT PILOTAGE


Two hundred and eighty cadets were given the following tests: (1) Eikonometer Test; (2) Leafroom Test; (3) Frontal Plane Apparatus Test. The amounts of aniseikonia found were very small. No relationship was found between aniseikonia and either: (1) pilot success or failure to pass course, (2) difficulty in landing. Nearly all cadets had less than 1% of aniseikonia.

1950

RIPPLE, P.H.
Wilson, M.R.

ANISEIKONIA IN AIR FORCE CADETS AND ITS RELATIONSHIP TO THE HOWARD-DULMAN DEPTH PERCEPTION TEST

No relationship was found.

1951 

**CIBIS, F.A.**

**THE EFFECT OF RETINAL ILLUMINATION ON VISUAL PERCEPTION OF SPACE: I. EXPERIMENTAL STUDIES RELATED TO A SPECIAL TYPE OF ANISEIKONIA**


Analysis was made of a special type of aniseikonia due to differences in retinal illumination, the state of refraction or in relational threshold of brightness. Spatial distortion and angular disparity between correlated boundaries of real and apparent patterns increase as differences in retinal illumination, refraction, and sensitivity to light increase. Threshold amplitude of depth discrimination remains constant.

1953

**ALTSHAN, A.**

**ANISEIKONIA AND THE HOWARD-DOLMAN TEST**


See abstract under Depth Perception and Stereopsis.

1953

**McFARLAND, R.A.**

**HUMAN FACTORS IN AIR TRANSPORTATION**


Page 138. "Present visual selection procedures (of aviation pilots) based on high visual acuity, low refractive errors, and good muscle balance would tend to eliminate subjects with over 1% of image disparity. There seems little justification for including tests for aniseikonia in routine selection, although they may be useful as diagnostic measures in examining borderline cases."

Also see abstract under Atmospheric Effects.

11. **AUTOKINESIS**

1962 **MILLER, E.F.**

**COMPARISON OF AUTOKINETIC MOVEMENT PERCEIVED BY NORMAL PERSONS AND DEAF SUBJECTS WITH BILATERAL LABYRINTHINE DEFECTS**


The main conclusion using 9 normal and 9 bilateral labyrinthine defective subjects was that the sensory organs of the inner ear are not essential for the perception of autokinetic movement.

1967 **PITTS, D.C.**

**VISUAL ILLUSIONS AND AIRCRAFT ACCIDENTS**


A complete discussion of spatial disorientation and autokinetin, cocolugyal, oculogravic and coriolis illusions is given. Proposed research is outlined and recommendations are given for minimizing the effects of illusions on the pilot. Darkness, inclement weather and emotional stress factors are discussed.

111. **CYCLOSIONAL EYE MOVEMENTS**

1838 **WHEATSTONE, C.**

**CONTRIBUTIONS TO THE PHYSIOLOGY OF VISION**

Phil. Trans. R. Soc., 371-394, 1838.

1840 **TOURNOUX, J.**

**BERICHT ÜBER DIE WERKTUNGEN IM GEBIET DER PHYSIOLOGIE DER SINNE, INSBESONDERE DES BEICHTSSINNES**

Muller's Arch. Anat. N. Physiol., 56, 1840.

1854 **GRAFEN, A. von**

**BETRACHT ZUR PHYSIOLOGIE UND PATHOLOGIE DER SCHIEFEN AUGENMUSKELN**


1961 **AUBERT, H.**

**EINE SCHEINBARE BEDEUTENDE DREHUNG VON OBJEKTTEN BEI NEUERUNG DES KOPFES NACH RECHTS ODER LINKS**

Virchows Arch., 20:381-393, 1861.

1865 **JAVAL, E.**

**DE LA NEUTRALISATION DANS L'ACTE DE LA VISION**


1868 **NAGEL, A.**

**ÜBER DIE VONKOMMEN VON Wahren BOLLungen DES Auges um die Gerichtslinie**

Arch. f. Ophthal., 14:228-246, 1868.
1870 Stewens, G.T.  
THE DIRECTIONS OF THE APPARENT VERTICAL AND HORIZONTAL MEDIANs OF THE RETINA  
Arch. Ophthalm. 26:181-203, 1897.

1900 Kopmann, F.R.  
UBER DIE DER WILKUR ENTGEGENEN FUSIONS- 
Bewegungen der Augen  
Arch. ges. Physiol. 80:1-40, 1900.

1913 Lindsay, H.W.  
AN INVESTIGATION OF THE LAW OF EYE MOVEMENTS  

1924 Deaklebs, A.  
A METHOD OF DETERMINING THE COMPENSATORY  
POSITION OF THE HUMAN EYE  
Acta Oto-laryng (Stockholm) 5:170-174, 1924.

1926 Ames, A.  
CYCLOPHORIA  

1928 Brown, C.G.  
PERCEPTION OF DEPTH WITH DISORIENTED VISION  

1928 Kompansets, S.  
INVESTIGATION OF THE COUNTER-ROLLING OF THE  
EYES IN OPTIMUM HEAD POSITIONS  

1929 Wilt, R.  
UBER OPTISCH ERZWUNGENE PAARLLELE ROLLUNGEN  
DER AUGEN  

1930 Fischer, M.Z.  
MESSUNGEN UNTERSUCHUNGEN LIBER DIE GEGENWÜRLUNG  
DER AUGEN UND DER HÖHVERÄNDERUNGEN DER SAMTLICHEN  
VERTIKALER BEI SEITLICHER NEITUNG DES  
GESAMTKÖRPERZS BIS ZU 360°  
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<tr>
<th>Year</th>
<th>Author</th>
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<tr>
<td>1932</td>
<td>Bensie, F.</td>
<td>Sensory in vision with no known eye defect.</td>
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<tr>
<td>1943</td>
<td>Lancaster, M.</td>
<td>Perception of visual rotation of the object.</td>
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<tr>
<td>1943</td>
<td>Gold, E.</td>
<td>Perception of visual rotation of the object.</td>
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**References:**
- Brain, E. (1932). Sensory in vision with no known eye defect. J. Physiol. 102, 319-344.
THE DEPENDENCE OF CYCLOPHORIA ON CONVERGENCE, ELEVATION AND THE SYSTEM OF AXES
Allen, M.J.

TORSIONAL MOTIONS OF THE EYEBALL
Fender, D.H.

STEREOPSIS AND VERTICAL DISPARITY
Olle, E.H.

ROLLING OF THE EYE AROUND ITS VERTICAL AXIS DURING NORMAL OCULAR MOVEMENTS
Gehman, J.

COMPENSATORY ROLLING MOVEMENTS OF THE EYE
Norton, P.A.

EYE MOVEMENT RESPONSES TO CONVERGENCE STIMULI
Westheimer, G.

RECORDING COMPENSATORY ROLLING OF THE EYES
Davies, T.
Norton, P.A.

A NEW AND OBJECTIVE METHOD FOR MEASURING OCULAR TORSION
Chabrier, A.
Wollner, R.C.

A CLINIC TECHNIQUE FOR MEASUREMENT OF EYE MOVEMENTS IN A DYNAMIC ENVIRONMENT
Frye, W.T.
Jones, G.M.

COUNTER-ROLLING OF THE EYES AND ITS DEPENDENCE ON THE MAGNITUDE OF GRAVITATIONAL OR INERTIAL FORCE ACTING LATERALLY ON THE EYE
Wollner, R.C.
Graybiel, A.

VISUAL INDUCTION OF EYE TORSION, AS MEASURED WITH AN AFTER-IMAGE TECHNIQUE, IN RELATION TO VISUAL PERCEPTION OF THE VERTICAL
Greenburg, C.

TWO STEREOSCOPIC MEASURES OF CYCLOTORSION OF THE EYES
Nabor, G.S.

ANALYSIS OF EYE MOVEMENTS DURING MONOCULAR AND BINOCULAR FIXATION
Krauskoff, J.
Cornsweet, T.H.
Riggs, L.A.

COUNTER-ROLLING OF THE HUMAN EYES PRODUCED BY HEAD TILT WITH RESPECT TO GRAVITY
Miller, E.P.
See abstract under Illusions and Visual Perception: Gravitational and Vestibular Effects.

ÜBER DEN EINFLUSS DER SCHWERERSTÖRUNGEN AUF DIE AugeKEDRÜCK UND DIE WAHRHEITSMERKE IM RAUM
Schück, H.

ON THE DEFINITION OF BINOCULAR DISPARITY
Wallach, H.
Lindauer, J.

THE MEASUREMENT OF EYE TORSION
Howard, J.P.
Evans, D.A.
1964 HOWARD, I.P.
Templeton, W.B.

VISUALLY-INDUCED EYE TORSION AND TILT
ADAPTATION


1964 KAUFMAN, I.

ON THE NATURE OF BINOCULAR DISPARITY


1964 KOHLER, I.

THE FORMATION AND TRANSFORMATION OF THE
PERCEPTUAL WORLD

Psychol. Issues 3 (Mono 12), 1964.

1964 LEIBOWITZ, H.

THE EFFECT OF Rotation AND TILT ON THE
MAGNITUDE OF THE Foggendorf ILLUSION


1964 MYNDRE, E.

LISTING'S LAW AND THE ROLLING COMPONENT OF
THE MOVEMENTS OF THE EYe


1966 MILLER, E.P.

Graybiel, A.
Kollogg, R.S.

OTOLITH ORGAN ACTIVITY WITHIN EARTH STANDARD,
ONE-HALF STANDARD AND ZERO GRAVITY ENVIRONMENTS

Aerospace Medicine, 37:399-403, 1966

1967 ADAMS, A.J.

Levane, J.B.

STEREOSCOPIC DEPTH ASSOCIATED WITH CYCLO-
TORSONAL EYE MOVEMENTS


See abstract under Depth Perception and Stereopsis.

1967 ALLEN, M.J.

Cartel, J.R.

THE TORSION COMPONENT OF THE NEAR REFLEX


1967 BUKIJEKSI, B.R.

TRAFFIC SIGNALS AND DEPTH PERCEPTION


1968 DIERER, F.

REGISTRATION OF CIRCULAR EYE MOVEMENTS


1968 FRIE, G.A.

NOMOGRAMS FOR TORSION AND DIRECTION OF REGARD


1968 JANKEE, J.B.

BARBERIA ROTATION IN COMBINATION WITH
SINUSOIDAL ROTATION ABOUT A VERTICAL AXIS

Acta Oto-Laryng (Stockholm), 65:244-250, 1968.

1968 OKADA, H.

A VERGENCE TEST, ESPECIALLY ON ABNORMAL
TORSONAL EYE MOVEMENTS


1968 QUERE, M.A.

et. al.

PSEUDO-TORSION OF OBLIQUE MOVEMENTS


IV. GRAVITATIONAL AND VESTIBULAR EFFECTS

1919 MURPHY, W.E.

OBSERVATIONS DURING EXAMINATIONS OF CANDIDATES
FOR THE AVIATION SERVICE


The examination consisted almost entirely of studying the "sense of
equilibrium" of the candidates, as this was believed to be the only
essential requirement for a pilot. No quantitative visual standards
were in force.

1946 GRAYBIEL, A.

THE ROLE OF VESTIBULAR Nystagmus IN THE VISUAL
PERCEPTION OF A MOVING TARGET IN THE DARK

Clark, B.
Hupp, D.R.
MacCorquodale, K.


Six subjects reported their visual impressions both during and
following rotation while observing a moving target in the dark and
in a lighted room. The target counter-rotates illusorily on rotation of the subject during acceleration and deceleration in the dark. The phenomenon did not occur in the lighted room.

1946 Clark, B. 
Graybiel, A. 
MacCorquodale, K.

THE ILLUSORY PERCEPTION OF MOVEMENT CAUSED BY ANGULAR ACCELERATION AND CENTRIFUGAL FORCE DURING FLIGHT: II. VISUALLY PERCEIVED MOVEMENT OF A FIXED TARGET DURING TURNS


Results show illusions of motion and displacement may occur during all degrees of bank from 10° to 60°, and always occurred during banks of 40° and above. There is a direct relationship between the degree of bank and amount of motion and displacement observed; the maximum observed displacement of the target from the "true" position was 50°. All displacements were observed in or close to the vertical plane, whereas motion was not only upward and downward, but to the right and left.

1946 Clark, B. 
Graybiel, A. 
MacCorquodale, K.

THE ILLUSORY PERCEPTION OF MOVEMENT CAUSED BY ANGULAR ACCELERATION AND CENTRIFUGAL FORCE DURING FLIGHT: III. HABITUATION AND TECHNIQUE OF ASSUMING THE TURNS AS FACTORS IN ILLUSORY PERCEPTION


No evidence of difference in illusory perceptions was found for different types of banking. Habitation did not occur.

1949 Brown, R.H.

THE RELATIONSHIP BETWEEN APPARENT DISPLACEMENT AND MOTION IN THE OCULAR TILTED ILLUSION


Twelve subjects were each placed in a Link Trainer at 26 r.p.m. for one minute. The subjects head was maintained at a fixed 15° forward inclination. In general, the target was observed as displaced and always in the direction of apparent movement. There were, however, large individual differences in reports of amount and duration of apparent displacement. For those who experienced apparent displacement of the target, the illusion persisted briefly after the apparent motion had ceased. Correlations of independently observed nystagmus was related to both. The relationship was more significant to rotation than displacement.

1949 Graybiel, A. 
Brown, R.H.

THE DELAY IN VISUAL ORIENTATION FOLLOWING EXPOSURE TO A CHANGE IN DIRECTION OF RESULTANT FORCE IN A HUMAN CENTRIFUGE

Joint Rep. 

Three subjects were exposed on the human centrifuge to a change in direction of resultant G relative to the body axis. Under the conditions of the experiment, a horizontal line appeared to rotate through an angle corresponding to the change in direction of the resultant force. The subjects task was to keep the line horizontal at all times. A marked discrepancy was noted between the time required to impress the physical force and the period during which he found it necessary to make adjustments in keeping the line horizontal.

This is explained as a measure in the delay in the subject's visual orientation to a change in direction of the resultant G. This is important in aviation as the full disorienting effects of a change in direction of the resultant G relative to the body axis will not become manifest if the exposure time is short.

1949 Mann, C.W.

THE PERCEPTION OF THE POSTURAL VERTICAL: II. VISUAL FACTORS

Proj. No. NR 140-455, 

There was no significant difference in the precision of the individuals judgement of the visual vertical and the visual horizontal. The mean errors and variability of judgement are significantly increased when a soft padded seat is substituted for a hard seat. The mean error and variability of judgements of the visual horizontal are significantly greater when the individual is in a position of tilt than when he makes the judgement from a vertical position.

1949 Noble, C.E.

THE PERCEPTION OF THE VERTICAL: III. THE VISUAL VERTICAL AS A FUNCTION OF CENTRIFUGAL AND GRAVITATIONAL FORCES


Three subjects took part in a variety of experiments in a human centrifuge provided with blackout arrangements and electrical devices for recording the angle of resultant force and the subjects determinations of the visual vertical. Results seem to substantiate Mach's hypothesis that subjects adjust the visual vertical as the resultant of the centrifugal and gravitational forces.
1949 Passey, G.E.  
THE PERCEPTION OF THE VERTICAL VI. ADJUSTMENT TO THE VERTICAL WITH NORMAL AND TILTED VISUAL FRAMES OF REFERENCE


Five subjects were required to adjust themselves to a vertical position in the presence of a visual frame of reference which was presented in alignment with gravitational vertical, and positions divergent from gravitational vertical. The relationships of findings to the theory of Koffka and others was discussed.

1950 Mamer, C.W., Ambler, R.K., Passey, G.E.  
THE PERCEPTION OF THE VERTICAL: VII. EFFECT OF VARYING INTERVALS OF DELAY IN A TILTED POSITION UPON THE PERCEPTION OF THE POSTURAL VERTICAL


After a 60 second exposure to tilt, there was a statistically significant increase in the average error of adjustment to the gravitational vertical. Also, a greater number of errors were made in the direction of the initial tilt. Twelve subjects were subjected to 45° tilts in either quadrant in a lateral plane for 0, 15, 30 and 45 seconds. With increased time of tilt there was an increase in the constant error in the direction of the initial tilt, but there was no increase in the variability of the data for average error, constant error, or number of errors in the direction of the initial tilt.

1950 Brown, R.H., Gandy, F.E., Jr.  
INFLUENCE OF VISUAL STIMULATION ON HABITUATION TO ROTATION


An investigation of habituation to rotation was made under three different conditions of stimulation. (Habituation to rotation = decrement in duration of post-rotational apparent motion of visual objects with repeated rotation.) Three groups of 12 subjects were exposed to identical conditions of rotation and visual stimulation on certain trials in a series of 20 rotational trials. The groups were compared on the basis of these conditions. Hence the treatment of each group was unique only with respect to trials interpolated between these comparison trials. Intergroup differences in stimulating conditions on these interpolated trials consisted of variations in the amount and nature of visual stimulation present to allow visual fixation of a target light. Whereas one group which had very little opportunity for fixation of the target during the 20 trials did not exhibit habituation, the others, with greater opportunity for visual fixation, did exhibit habituation.

1951 Ray, J.T.  
THE PERCEPTION OF THE VERTICAL XI. THE POINT OF SHIFT FROM VISUAL TO POSTURAL FRAMES OF REFERENCE


The relative importance of visual and postural factors in the judgement of the vertical is discussed. Four subjects, each making 195 judgements were used. The postural vertical did not differ significantly with the true gravitational vertical under any condition. The judged vertical deviated increasingly from the true gravitational vertical as target displacement from its true position was increased.

1952 Gerathewohl, S.J.  
PHYSICS AND PSYCHOPHYSICS OF WEIGHTLESSNESS VISUAL PERCEPTION


The paper predicts theoretical conclusions concerning the interaction of proprioceptive and visual senses under conditions of subgravity and zero gravity. It is shown how the predictions seem to have been borne out.

1952 Boring, R.O.  
THE EFFECT OF VISUAL STIMULUS VARIABLES UPON THE PERCEPTION OF THE VISUAL VERTICAL


The paper is concerned with a suggestion by J.J. Gibson that when main lines of the visual field are parallel to the direction of the gravitational force, even though the head or body is tilted, there will be a consistency between visual and proprioceptive cues which yields an invariant resultant. When, however, the visual field is tilted relative to gravitational vertical, judgements of the latter will be less precise and more variable. The experimental results in this paper do not support this theory.

1952 Clark, B., Greybiel, A.  
ILLUSORY PERCEPTION OF ROTATION FOLLOWING CONSTANT TURNS IN A LINK TRAINER


The illusory perception of rotation was studied in a modified Link Trainer using 31 flight students as subjects. The duration of the illusory effects following rotation increased sharply as the period of constant rotation increased up to 30 seconds and thereafter increased slowly to 2 minutes. The implications of the results are discussed.
1952 Gravel, A. 
OCULOGRAPHIC ILLUSION
A general investigation including some results with after-images and effects of body position. It was found that the important variables determining the appearance of the illusion were:
1. the pattern of centripetal acceleration.
2. the position of the subject.
3. The visual framework.

1954 Cohron, L.B. 
VARIATION IN HUMAN G TOLERANCE DUE TO POSITIVE ACCELERATION
The report concerns the determination of G tolerance levels with regards to loss of peripheral vision, blindness and unconsciousness. One thousand subjects, seated in an upright position, were used to establish the following thresholds:
4.1 ± 0.7 G — loss of peripheral vision
4.7 ± 0.8 G — visual blackout
5.4 ± 0.9 G — unconsciousness
Similar visual symptoms do not occur as readily with transverse, i.e., back to chest, G forces until over 12 G. (Refs: Cawor, O. and S. Ruff, Die ertraglichkeitgrenzen fur flugmechanische schad, Luftfahrtmedizin, 3:225-230, 1939.)

1956 White, W.J. 
THE EFFECTS OF GRAVITATIONAL STRESS UPON VISUAL ACUITY
A determination of the relationship between increased gravitational force and visual acuity was made when the factor of reduced cerebral circulation is minimized by the use of protective measures known to ameliorate the gross visual symptoms associated with gravitational stress. It was found that gravitational stress has a significant and progressive effect on visual acuity. An hypothesis is advanced to account for this observation.

1958 Brown, J.L. 
EFFECT OF POSITIVE ACCELERATION ON VISUAL REACTION TIME
The build-up and decay of acceleration followed a sinusoidal function. The reaction time was prolonged by the action of acceleration on the visual system.

1958 White, W.J. 
ACCELERATION AND VISION
A review and evaluation of research pertaining to the effects of acceleration on human vision, including an extensive bibliography.

1960 White, W.J. 
VARIATIONS IN ABSOLUTE VISUAL THRESHOLDS DURING ACCELERATION STRESS
Measurements were made of the absolute threshold of foveal (cone) and peripheral (rod) vision within the range of 1-4 G. Dislocation of the visual function was studied selectively by the use of anti-G suits. It was concluded that:
1. Acceleration levels of 3-4 G approximately double and triple foveal thresholds respectively.
2. Threshold levels in peripheral vision triple at 3 G and quadruple at 4 G.
3. A rise in threshold (decrease in sensitivity) was found with repeated exposure to acceleration, the rise being smaller than that associated with the acceleration.
4. The rise in acceleration in peripheral thresholds is, in part, compensated for by anti-G suits.

1961 Pigg, L.B. 
THE EFFECT OF TRANSIENT WEIGHTLESSNESS ON VISUAL ACUITY
The visual acuity was measured of subjects while exposed to short periods of weightlessness aboard an aircraft flown through "zero-G" trajectories involving transition from 1 G to 2 1/2 G to zero-G. Monocular and binocular acuity of far and near vision were measured on both Snellen and chequerboard targets. Control measurements were made on the ground and in flight at 1 G in a counterbalanced sequence with the zero-G measurements. The results show that the weightless environment produced for this study has a detrimental effect on visual acuity as measured. The decrement is not considered to have a practical significance, the loss of visual acuity of zero-G was 0.1.

1962 Miller, E.P. 
COUNTER-ROLLING OF THE HUMAN EYES PRODUCED BY HEAD TILT WITH RESPECT TO GRAVITY
A method is described to measure compensatory torsion to within + 5.3 minutes of an arc. Torsional eye movements, compensatory to head tilt, were found in all planes except the sagittal. Counter-rolling was always opposite to the lateral component of head tilt, and increased up to a maximum for head inclination of 60-90°, being zero when the head is vertically down. No relationship was found between the amount of counter-rotation and the order in which the measurements were made. A theory is advanced to account for the findings.

1962 Hammer, L.R. Perception of the Visual Vertical Under Reduced Gravity

Judgments of the vertical were made in an unstructured visual field while in flight and under 4 levels of gravity ranging from 1-4 G. Sixteen subjects made 5 judgments in each of 4 G conditions. A 1.8° error at 1 G was found to increase to 3.5° at zero-G. Conditions associated with in-flight research were discussed, and suggestions for future research were presented.

1963 White, W.J. Vision and Unusual Gravitational Forces
The paper gives a review and evaluation of research and observation, the major topics being increased G and null gravity. The operational experience of astronauts is included, and the techniques for minimizing undesirable effects are summarized.

1965 Miller, E.F. Visual Localization of the Horizontal As a Function of Body Tilt Up to 90° from Gravitational Vertical
Fromly, A.R. Graybiel, A. van den Brink, G.
The visual horizontal was determined for 3 sophisticated subjects tilted laterally in 10° intervals within ± 90° from the gravitational vertical. The deviation at 10-20° either side of vertical was not significant from that of upright. Inclinations beyond this caused the E-phenomenon to appear and increase bilaterally to maximum about the 40-50° position. (The E-phenomenon is the tendency of the apparent visual horizon to incline in the same direction as the body tilt.) With further inclination the deviation was found to reverse direction and pass through the position of zero deviation (60-80°) to grow as the A-phenomenon. (The latter is the opposite of the E-phenomenon.) The responses were bilaterally symmetrical.

1966 Miller, E.F. Magnitude of Gravitoinertial Force: An Independent Variable in Egocentric Localization of the Horizontal
The direction of gravitoinertial force, i.e. resultant of gravitation and induced centripetal force vectors, was held constant while the magnitude of force varied 1-2 G. The effect of the egocentric localization of the horizontal was measured in 8 normal and 2 labyrinthine defective subjects. The egocentric visual localization of the horizontal deviated from gravitoinertial horizontal as a function of gravitoinertial force; it increased with the amount of body tilt from its alignment with the resultant force. Normal subjects manifested increasing amounts of E-phenomenon; defectives varied from A to E. Roles of otolithic and nonotolithic gravireceptor cues in visual localization in absence of empirical visual cues are discussed.

1967 Graybiel, A. Vestibular Experiments in Gemini Flight V and VII
Astronauts were exposed to weightlessness for 8 days in CT V and 14 days in CT VII. The task was to set a dim line of light in a dark field to an external horizontal reference both pre-, post- and during flight. The most significant finding was the high degree of accuracy in the settings made, suggesting that even without otothot function the central nervous system still maintains accurate visual direction of space. No significant differences between pre- and post-flight responses were found.

1967 Pitts, D.C. Visual Illusions and Aircraft Accidents
See abstract under Illusions and Visual Perception: Autokinesis.
A survey of the literature is given and then a summary of the conclusions of a paper in AERONAUTICS, Vol. VI, 9-60, 1958:
1. Most young people accommodate 0.25-1.75 D in an empty visual field.
2. Some young people showed equal accommodation when the extension of the empty visual field was 20° or over 180°.
3. Some young people showed equal accommodation when illumination of the empty visual field is 1.2 or 500 lux.
4. A window frame or dashboard did not produce any stimulation to accommodation.
5. When colored filters are used to look at an empty visual field, chroma perception diminishes and is often followed by perception of dark grey or even blackness.

1961 BROWN, J.L. SENSORY AND PERCEPTUAL PROBLEMS IN SPACE FLIGHT


A general review of the problems of space flight is given. Space myopia should not be a problem as the stars will be an adequate stimulus for accommodation.

Also see abstract under Space Flight, Including Reconnaissance and Surveillance.

1961 LUDVIGK, E. THE PERCEPTION OF MOVEMENT PERSISTENCE IN THE GANSEFIELD


The subjects observed movement of a single, black, spherical stimulus in a Gansefield and reported when the movement stopped. Time between real and apparent cessation was called the 'time delay'. The following formula was proposed:

\[ t = r + \frac{1}{av^2} \]

where
- \( t \) = time delay
- \( r \) = reaction time
- \( a \) = constant of inverse proportionality
- \( v \) = velocity

A stimulus traveling at high speed for relatively long periods produces greater perception of velocity than one slower and perceived for a shorter length of time. This is because if the former is suddenly stopped, the contrast is more obvious.

1962 HEATH, C.C. THE TIME COURSE OF NIGHT AND SPACE MYOPIA

The refractive state of the human eye was measured over periods up to 4 hours in total darkness and in an empty, lighted visual field, using a subjective optometer, an infrared retinoscope, and infrared automatic recording optometer and white light, and infrared photography of the third Purkinje image. Under both viewing conditions, the measurements showed a continuously varying relative myopia produced by accommodative changes, which tended to increase during 3-5 minutes, thereafter with continuous, irregular, rapid fluctuations of as much as 0.75 D, occasional spontaneous changes of the predominant level of up to 1.50 D over periods of up to 2 minutes. This highly dynamic accommodative activity in an empty visual field contrasts with previous concepts of a passive and relatively fixed "resting state" of accommodation under such conditions. Factors influencing this accommodative activity were also studied.

1962 MILLER, J.W.
HALL, R.J.
THE PROBLEMS OF MOTION PERCEPTION AND ORIENTATION IN THE CANSEFIELD


The same apparatus is used as Miller and Ludvig used in 1958. (See this section.) A distinction between the Cansefield and absolute darkness is drawn. Results indicate there are marked individual biases whether the perceived center appears to the right or left of the true center. Most subjects reported they fixated on a point in space they thought was center and moved the target to the point. The subjects also resorted to orientation cues from different parts of their bodies as well as any proprioceptive cues from the extraocular muscles. It seems that a subject can detect a 2-3° movement from "something".

1962 TEPLAS, D.J.
THE ELECTROPHYSICAL CORRELATES OF VISION IN A UNIFORM VISUAL FIELD


The hypothesis that high alpha activity is an important indicator of blackout susceptibility is not strongly supported.

The role of instruction

1952 BORING, R.O.
KEMP, C.W.
THE ROLE OF INSTRUCTION IN EXPERIMENTAL SPACE PERCEPTION

1946  GRAYBIEL, A. 
Clark, B. 
Hopp, B.I. 
MacCorquodale, K. 

The Role of Vestibular Nystagmus in the Visual Perception of a Moving Target in the Dark 


See abstract under Illusions and Visual Perception: Gravitational and Vestibular Effects. 

1957  ADRE~ H.W. 
GRAYBIEL, A. 
Morill, S.N. 
Torchurst, G.C. 
Riven, J. 

Nystagmus Elicited by High Intensity Sound 


In order to study some of the extra-auditory effects of loud noise, deaf subjects were stimulated by high intensity sound, both pure tone of several frequencies (100-3,000 cycles per sec.) and wide band noise. In those showing positive response to vestibular stimulation in one or more of the standard tests, nystagmus was a regular consequence when the noise was of a sufficiently high intensity. Curves are shown, comprising the thresholds at 6 frequencies of pure tone and for the noise of a jet engine. Distress and apparent movement in the visual field were in some cases regular concomitants of nystagmus. 

1961  SCHUMANN, H.P. 

Visual Acuity and Ophthcmcthic Nystagmus 


The paper gives a good review of the topic. It includes inversion, i.e. reversal of the movements, Goldmann eye pendulum, and the Guenther method. The Goldmann eye pendulum is probably the most accurate objective method. 

1919  CAMPBELL, K. 

Heterophoria with Special Reference to Flying 


The article suggests that a certain number of bad landings may be attributed to heterophoria. Tests for heterophoria are discussed, together with prismatic treatment of any deviations. 

1919  HOWARD, H.J. 

A Test for the Judgement of Distance 


One hundred and six subjects were used. The best performers with the apparatus had either no muscle imbalance or esophoria, none bad exophoria. 

Also see abstract under Depth Perception and Stereopsis. 

1923  BERENS, C. 

The Eye in Aviation: Some Experiences in the Work of the Department of Ophthalmology, Medical Research Laboratory, Third Aviation Instruction Center, A.E.F., France 


The article claims to contain a complete bibliography. The present standards (1923) are given in which, "... it seems that the converging power should never be less than double the diverging power at all distances." 

Also see abstract under Visual Standards. 

1923  LANCET 

Ophthalmology in Relation to the Navy, Army and Air Force 


It is stated in the symposium that in the First World War an exophoria of 2 1/2 degrees of esophoria of 1 1/2 degrees was unsatisfactory. 

In the discussion, J.F. Carruthers said he could substantiate what Clements had found with respect to orthoptics greatly helping bad landers. 

1923  BRITISH JOURNAL OF OPHTHAMOLOGY 

Section of Ophthalmology. Discussion on Ophthalmology in Its Relation to the Navy, Army and Air Force 

It is stated that 1/2° of esophoria or exophoria at distance with
the red-green test is "not considered good". The paper is an
eexample of collective opinion rather than experimental results.

Also see abstract under Flash Blindness, Clare and Radiation Effects.

1925 CLEMENTS, E.C.
VISUAL PROBLEMS IN REGARD TO FLYING AND
INDUSTRIAL FATIGUE FROM A SERVICE STANDPOINT


An investigation, "revealed that between 75% and 80% of the flying
accidents sent to the hospital from neighboring training schools
were the result of unsuccessful attempts at landing". The author
delineates the visual requirements as to whether a candidate will
be a successful flyer, especially in landing. Flying places the
pilot into a world of "altered conditions", those of which are
primarily visual in character. Heterophoria contributes to the
number of accidents; and it may cause nervousness and fatigue from
unconceived strain.

1927 LOT, A.W.
DISQUALIFYING EYE MUSCLE IMBALANCES IN AVIATION


The report presents a diagrammatic representation of the disqualifying
eye muscle imbalances for USNFA. The standards (1927) were as follows:
Candidates were disqualified if they had-
1. Prism divergence less than 2°.
2. Prism divergence less than 4°, associated with esophoria
greater than 4°.
3. Prism divergence greater than 9°, associated with angle of
corvergence near 40°.
4. Prism divergence greater than 15°.
5. Esophoria greater than 2° at 6 m associated with:
   (1) angle of
corvergence near 40° (2) diplopia in lateral positions on the
tangent curtain.
6. Esophoria greater than 5° at 6 m.
7. Esophoria greater than 12° at 33 cm.
8. Esophoria greater than 4° at 6 m associated with:
   (1) diplopia
   in lateral positions of the tangent curtain (2) accommodation of
   1 D below or above Duane's table (3) hyperopia near the disqualifying
   limit (4) prism divergence less than 4°.
9. Esophoria greater than 10° at 6 m.
10. Hyperphoria greater than 0.75° for an applicant.
11. Hyperphoria greater than 1° for a qualified pilot.

1930 THORNE, F.H.
A REVIEW OF OCULAR MUSCLE IMBALANCE (WITH
REPORT OF TWO-HUNDRED AND FORTY-FOUR CASES)

3 Refs. Military Medicine, 56:175-205, 1930.

The qualifying limits concerning ocular muscle imbalance are not
rigid. In fact, "an individual may exhibit an imbalance bordering
upon a square before he is disqualified for flying training, provided
other pertinent factors are normal". The field of binocular fixation
must be maintained 50° from the primary position of gaze; beyond 50°
diplopia is of little significance. The existence of a cyclophoria
is not investigated as a routine, but only when considered necessary
by the examiner. "It is the generally accepted theory that many
cases of latent and manifest deviations are accommodative in origin.
It is believed, however, that all latent cases exist independent of
refractive errors, and that the errors, when fatigue is superimposed,
only exaggerate the defect without being the primary cause." Uncorrected
refractive error is believed to be the most common cause of increasing
the tendency of a latent deviation and production of muscular asthenopia.
The accommodative theory of orthophoria, esophoria and esophoria are
discussed. Of 244 applicants exhibiting horizontal deviations, 95.9% were
associated with refractive errors above 0.25 D, and 72.5% were
eliminated. Of a total of 500 applicants examined, 69.7% were relieved
from flying because of inability to make proper progress. The Haddon
Rod Screen Test is a standard for Air Corps measurement of heterophoria,
other tests are discussed. A review of the defects which disqualify
applicants from flying is given.

1931 ARMY MEDICAL BULLETIN THE SELECTION OF THE AVIATOR


The report describes the methods of measuring the visual parameters
in full. Orthophoria is defined (at 20 feet) as being no deviation
at all or any deviation less than 2° of esophoria, 1° of exophoria
or 1/2° of hyperphoria. It is stated then, "the associated factors
are vitally important in determining the significance of heterophoria."
Examples of these "associated factors" are, powers of abduction and
adduction, associated parallel movements, accommodation, errors in
refraction and the power of fusion.

1931 McALESTER, A.W.
BALANCE OF THE OCULAR MUSCLES AS RELATED TO
FLYING SOME CONSIDERATIONS


The article discusses early methods of investigation of ocular
muscle balance. A man should not be allowed to enter the service
with a hyperphoria of 1°.
Also see abstract under Visual Standards.

1942 GILLESPIE, C.E.
AVIATION OPHTHALMOLOGY

The exophoric pilot "will run his nose into the ground", whereas the exophoric pilot may think the ground is nearer than it is.

1943 ABRAHAM, S.V. NEAR HORIZONTAL PHORIA AND DIVERGENCE TESTS

Four thousand subjects were used and typical cases are presented to show how the findings from near horizontal phoria and divergence tests fall into 3 characteristic groups. The relation of the base-in reading at 13" to the interpupillary distance is emphasized. The effect of cycloplegia on the findings is shown not to be dependable, even though the tendency for cycloplegia to cause a reduction in the convergence activity is suggested.

1943 KANE, A.L. CORRELATION OF EFFECTIVE VISUAL ACUITY AND POOR OCULAR MUSCLE BALANCE ON ABILITY TO SUCCIND IN FLYING TRAINING

No Refs. Canada, R.C.A.F., Director of Medical Services, Great Britain, O.S.R.D. No. III-1-2233, April 1943.

The report shows no relationship between small 'phorias or convergence and the ability to fly, although the washout rate increases directly with a lowered visual acuity.

1944 SCOBEE, R.C. THE EFFECT OF EXHAUSTION AND MODERATE ANOXIA ON OCULAR MUSCLE BALANCE


See abstract under Atmospheric Effects.

1944 SCOBEE, R.C. AN ANALYSIS OF THE CYCLOTHALIC PORTION OF THE "64" EXAMINATION; (1) MUSCLE BALANCE


The requirements when the paper was written were heterophoria and prism divergence determinations at 20 feet—the only test at near fixation being the near point of convergence (Pc and PcB). One hundred and fifty subjects were used. The measurement of the near point in considered too inaccurate to be worth measuring; it is recommended that the heterophoria and prism divergence should be measured at near. The study agrees with that of Abraham (6,000 subjects were used) who found that prism divergence, not the absolute value of heterophoria is the factor on which heteropic symptoms depend. Tables are given comparing Abraham's and this study's heterophoria and prism divergence means at 13 inches. New standards are suggested to which candidates should conform for prism divergence and heterophoria at 13 inches.

1945 ROYAL CANADIAN AIRFORCE VISUAL FACTORS IN AIRCREW SELECTION


Ocular muscle balance findings (with the exception of relatively high hyperphoria at 15 inches) and relatively high convergence insufficiency or excess are not related to flying performance.

1945 SCOBEE, R.C. A COMPARISON OF TESTS FOR HETEROPHORIA


Tests compared are:

At distance 20 feet—(1) Maddox rod (2) von Graefe prism (3) subjective and objective cover test.

At distance 13 inches—(1) Maddox rod (2) von Graefe prism (3) Maddox wing (4) Thorington test (5) subjective and objective cover test.

It is recommended that the Maddox rod test at 20 feet is the best when both ease of performance and relative accuracy are concerned. Although it is admitted the subjective and objective cover test are the most accurate, they take too long to perform.

1945 SCOBEE, R.C. A COMPARISON OF TESTS FOR HETEROPHORIA: RELIABILITY OF THE SCREEN-MADDUX ROD TEST


Using sixty subjects it was found that there is no significant difference in heterophoria measurement when made with the screen-Maddox rod test in a lighted room or in the dark.

1945 SCOBEE, R.C. A COMPARISON OF TESTS FOR HETEROPHORIA: RELIABILITY OF THE SCREEN-MADDUX ROD TEST


One hundred and thirty-one subjects were used. Two examiners examined each subject on each of two different days. A reliability coefficient of 0.95 was found for lateral heterophoria measurement. A table is
Included of the distribution of horizontal phorias among the subjects, but the subjects were all aviation cadets and not a sample of the general population.

1945 SCOBEE, R.C. A COMPARISON OF TESTS FOR HETEROPHORIA
Green, E.L. Variations in the screen-Maddox rod test due to ocular dominance, red color, and screening
Moss, U.L.


Conclusions:
1. 0.4° more esophoria is produced at both 20 feet and 13 inches when screening is used in conjunction with a Maddox rod—no matter whether the rod is red, white or placed before the dominant or non-dominant eye.
2. No significant difference in the results is obtained when the rod is placed before the dominant or non-dominant eye at either 20 feet or 13 inches. This contradicts results found by P. Dolman whose paper was the basis for placing the rod before the non-dominant eye in the old standards. Hence the test for dominance should be dropped from the standards and the rod placed before the right eye.
3. About 0.25° less esophoria is found at 20 feet with a white Maddox rod. There is no significant difference at 13 inches. Hence a white Maddox rod should be used.

1945 SCOBEE, R.C. AN ANALYSIS OF THE OPHTHALMIC PORTION OF THE "6A" EXAMINATION. (2) MUSCLE BALANCE-A SUMMARY OF SUGGESTED CHANGES


Additional conclusions to his work in 1944 (see above) are given. Prism divergence should be measured at 13° instead of 20°—the minimum should be 15° at 13°. Heterophoria should be measured at 13° as well as 20°—with limits of:
1. exophoria less than 15°.
2. esophoria less than 10°.
3. hyperphoria not more than 1.5°.
The Maddox rod (white) should always be placed before the right eye and the test for the dominant eye omitted (these recommendations now apply).

1946 KIRSCHBERG, L.S.S. DEPTH PERCEPTION AND FLYING ABILITY


No relationship was found between depth perception scores, hetero-
1951 HOFFME, E.H. VISUAL PROBLEMS OF PILOT IN PRONE POSITION None, H.W.
See abstract under Displays and Visual Simulation.

The usual tests administered are too subjective and the apparatus employed makes observation of the eyes impossible, e.g., phorometer and Orthotester. The latter is of no clinical value. Emphasis is placed on the cover test to detect muscle imbalances (subjective) rather than the Maddox rod, which is too subjective and the conditions are too artificial. Undue emphasis has been placed on the importance of the near point of convergence, and the point-to-nose exercises were given too indiscriminately. To detect whether responses are true or false, the examiner should constantly examine the positions of the corneal light reflexes. The red lens test is entirely subjective, subjects may even close one eye to avoid diplopia, or it may elicit heterophoria like the Maddox rod. Measuring phorias without ductions is valueless, phorias and ductions should be measured at different distances. Orthoptics may enable a candidate to pass an aviation eye exam but improvements usually are only temporary.

Experiments were done to determine whether large near phorias exist among pilots who were screened by the required visual tests. The four methods used were:
1. von Graefe prism
2. Maddox rod
4. Benham monocular projections

Although the test-retest reliability of most of these tests was found to be satisfactory, the actual values measured by the different tests varied considerably. Graphs are included showing the frequency distributions of the phorias both at near and far. The heterophorias at near varied between 16° esophoria and 19° exophoria.

See abstract under Atmospheric Effects.

Twenty-eight subjects were exposed for 3 to 6 hours to three different concentrations of ozone, namely: 20 ppm, 35 ppm and 50 ppm by volume. Heterophorias changed +4 1/4°. The possibility of contaminant formation in spacecraft and the effects on vision are discussed at some length.

Also see abstract under Atmospheric Effects.

See abstract under Depth Perception and Stereopsis.

Two papers are included, the first discusses the possibility of producing a fully automated screening device to detect both the fusion status and the deviation in the primary and other directions. The second discusses laboratory measurements of ocular muscle balance.

Also see abstracts under Color Vision, Dark Adaptation, Depth Perception and Stereopsis, Refractive Error and Refraction, and Visual Acuity-Static.
1968 OHLBAUM, M.K.

THE EFFECTS OF ALTITUDE ON CERTAIN ASPECTS OF VISUAL PERFORMANCE

26 Refs. M.S. Thesis, Division of Optometry, Indiana University, June 1968.

See abstract under Depth Perception and Stereopsis.

1969 LURIA, S.M.

THE RELATION OF "DUCTION" TO DYNAMIC STEREO ACUITY


See abstract under Depth Perception and Stereopsis.

1939 ARMSTRONG, H.C.

PRINCIPLES AND PRACTICE OF AVIATION MEDICINE

The Williams and Wilkins Co., Baltimore, Md., 1939.

P. 324-5 In considering the effects of atmospheric pressure change on the eye, no objective or subjective change was noted except for injection of the bulbar conjunctiva accompanied by a smarting or burning sensation. This holds presumably up to about 30,000 feet. Also see abstract under Visual Standards.

1947 LYONS, R.E.

ANALYSIS OF THE CAUSES OF DISQUALIFICATION OF 164,687 APPLICANTS REJECTED FOR AVIATION TRAINING


From July 1, 1943 to June 30, 1944 the initial examination on aviation applicants was on WDAGO Form 64 under the provisions of Army Regulation 40-110. From July 31, 1943 to February 17, 1944 applicants were examined under the provisions of AR 40-105, AR 40-110, and relaxed standards in WD circular 176, July 31, 1943. The latter included: V.A. 20/30 correctable to 20/20 O.U., heterophoria within 12° esophoria and 7° exophoria. During the year July 1, 1943 to June 30, 1944, 374,658 applicants were examined of which 164,687 (44%) were disqualified. Of each hundred disqualified, 29.7 did not pass the eye examination, 11.5 had defective V.A., 8.9 defective heterophoria, 7.5 defective color vision and 2.2 had an accommodative defect.

1950 AUGUST, J.

PHYSIOPATHOLOGY OF THE FLYERS EYE

Herder, A.

Physiopathology of the flyer's eye


This book is an extremely good source for the subject up to 1950.

1. Effect of altitude on visual apparatus—circulation of retina, ocular tension, pupillary reactions, V.A., visual fields, stereoscopic vision, accommodation, motility, color sense, and night vision (due both to decompression and anoxemia).

2. Visual troubles due to accelerations.

3. Effects of physical factors—light, cold, wind-blast, and vibration.

4. Vision and orientation in the altitude.

5. Wounds and burns.

6. Ocular psychoneurosis in aviation.

7. Intoxication.

8. Protection of the flyer's eyes.
9. Visual problems in aircraft design—field of vision, optical properties of windows, etc., arrangement of instrument panel, illumination of cockpit and instrument panel.

1962 SATLOW, W.P. SPACE RADIATION GUIDE
Carriger, A.W.
Klaven, C.J.
Kinner, D.H.


See abstract under Flash Blindness, Glare and Radiation Effects.

1968 PEACOCK, G.R. LASER PROPERTIES AND EYE HAZARDS (INTERIM REPORT)
Van No, V.


The relation between laser output properties and eye injury are described. A review of laser eye injury data is included together with certain aspects of laser safety.

1968 MARTIN, B.C. EYE OPAECITIES IN FLIGHTING PERSONNEL
Treadel, T.J.
Culver, J.P.


A summary is given of an 11 year period of eye opacities found after referral to the School of Aerospace Medicine, Brooks AFB, Texas. The ophthalmology branch saw 3,067 patients, 13% of whom had opacities. These were subclassified as follows, Lenticular-73, Corneal-49, and Vitreous-12. Details of types of the above opacities and the numbers grounded are given. The etiology of the opacity is reported, if known.

1968 LAPPIN, F.M. ANALYSIS OF THE FIRST THERMAL NUCLEAR PULSE AND ASSOCIATED EYE EFFECTS
Adams, C.F.


See abstract under Flash Blindness, Glare and Radiation Effects.
XVI. REFRACTIVE ERROR AND REFRACTION

1945 HIRSCH, M.J.

RELATION OF VISUAL ACUITY TO MYOPIA


The visual acuity and degree of myopia was measured for 64 eyes. The myopia was within a range of 0.50-13.50 D; all the subjects were college students. The log of the visual acuity plotted against the myopia gives the coefficient of correlation of 0.95. The results are important in guarding against over-correction of myopia, malingering, etc.

1966 USAF SCHOOL OF AEROSPACE MEDICINE

LECTURE OUTLINES


Lectures are included on refraction and refractive errors.

1968 WELCH, M.A.

THE MEASUREMENT OF VISUAL FUNCTION (SYMPOSIUM) PROCEEDINGS OF SPRING MEETING 1965


A paper is included on the clinical and laboratory measurement of refractive error.

Also see abstracts under Color Vision, Dark Adaptation, Depth Perception and Stereopsis, Ocular Muscle Balance, and Visual Acuity-Static.

1969 DUNST, J.L.

AN ANALYSIS OF SOME REFRACTIVE ERROR TRENDS IN U.S. AIR FORCE PILOTS AND NAVIGATORS


There are no fusional amplitude standards. Hence, it is possible to have qualifying heterophoria yet poor fusional amplitude reserves to maintain single binocular vision and vice versa.

XVII. SPACE FLIGHT INCLUDING RECONNAISSANCE AND SURVEILLANCE

1957 HAMILTON, C.E.

THE EFFECT OF A HORIZON-LINE LUMINANCE GRADIENT UPON TARGET DETECTABILITY IN ITS VICINITY


See abstract under Flash Blindness, Glare and Radiation Effects.

1958 BOYNTON, R.M.

LABORATORY STUDIES PERTAINING TO VISUAL AIR RECONNAISSANCE

Elsworth, C., Palmer, R.M.


The third and final report is presented on a program concerning the investigation of relevant variables involved in visual reconnaissance. A mathematical relationship is worked out which yields the contrast required for 60% recognition as a function of subject-target distance, exposure time, and number of confusion forms (struniforms) among which the critical target may be located. By translating altitude into experimental distance, aircraft velocity into viewing time and conditions of viewing (including meteorological conditions) into contrast, predictions are made about how performance should vary as a function of altitude from 500–30,000 feet. Further studies are reported of a preliminary attempt to understand individual differences in searching ability as they relate to parafoveal form recognition, visual acuity and eye movements.

1961 BROWN, J.L.

SENSORY AND PERCEPTUAL PROBLEMS IN SPACE FLIGHT


The paper gives a general review of the problems of space flight. It says space myopia should not be a problem because the stars will be an adequate enough stimulus for accommodation. Also covered in the paper are vision, hearing, vestibular senses, other senses, and other problems including time perception and sensory deprivation.

1962 JONES, E.R.

VISION AND THE MERCURY CAPSULE

Khan, W.H.


See abstract under Displays and Visual Simulation.
1962 MULLER, J.W. (Ed.) — VISUAL PROBLEMS OF SPACE TRAVEL —

The book is a good reference book although it is all conjecture and simulation. The following are discussed:
P. 3-4: Colors seen on the launching and in space.
P. 14: Discussion of simulated gravity.
P. 20-24: Visual displays with consideration for the various novel problems of space flight e.g. absence of gravity, presence of various accelerative forces.
P. 29-37: Vision at various stages in space flight.

1962 MORRIS, P.M. — VISUAL ASPECTS OF SPACE FLIGHT —

The paper is an introduction to the visual problems likely to be encountered in space, e.g. glare, retinal burn, weightlessness, space myopia, etc.

1963 NARVA, M.A. — VISUAL SURVEILLANCE AND RECONNAISSANCE FROM SPACE VEHICLES —

The review includes the variables affecting surveillance. An analysis of the theoretical capabilities of direct, unaided vision and neuroptic vision are presented.


A comparison is made between the actual visual capabilities and the predicted capabilities. Requirements for further study are discussed.

1967 TAYLOR, J.H. — VISUAL PERFORMANCE ON THE MOON —

Man will depend largely on his visual sense when he is on the moon. Many of the usual visual cues will be modified or absent on the moon, e.g. size, distance and color of the lunar features without aerial perspective, reference objects and other cues. There will also be harsh luminance contrasts. Photographs showing the effects on the lunar surface of the illumination and reflection from the

1967 BROWN, J.L. — THE VISUAL REALM IN SPACE FLIGHT —

A very useful résumé of visual problems in space is presented in the report. "... for his size, mass and energy requirement ... (man) ... can handle a broader range of situations more effectively and with more flexibility than any automatic equipment which might be designed." For an object that subtends 1° at the eye, its dimension in feet equals 1/2 its distance in miles. Gravity, both higher and lower than one G, is also considered. Effects of hyper-oxygenation and a discourse on the visual environment of space are included. The report concludes that the characteristics of the human visual process will probably remain unchanged in spaceflight except at very high acceleration or in a low oxygen atmosphere.

1968 CULVER, J.F. — THE HUMAN EYE IN SPACE EXPLORATION —
15 Refs. 4th International Symposium from Chap. XVIII In Bioastronautics and the Exploration of Space, Roadman, Strughold and Mitchell, 1968.

The various defects which it was prophesied would be produced in the visual system in space have not occurred, e.g. space cataracts and illusions. A table is included of the primary parameters of the visual environment of space including 90° solar illumination, surface reflectance and mean atmospheric transmission for the earth, EVA, Marx and the moon. Also included is a table showing critical visual tasks on the Apollo mission. "... daytime illumination at the moon's surface exceeds that on the earth by about 3X and the nighttime illumination facing the earth is approximately 60 times that of the earth due to the earth's reflectance."
The effects of training the dynamic visual acuity of 200 Naval Aviation Cadets were found to be substantial at high angular velocity of test objects, in absolute or percentage terms. At 110° per second, the amount of improvement and the rate of improvement varied greatly among the subjects.

The report shows how the visual acuity deteriorates at the angular velocity of the test object, travelling in a vertical plane, is varied between 20° per second and 160° per second.

The concept of "ease of seeing", E, is advanced.

Dynamic visual acuity tested with a rotary prism was compared with that measured with a rotation mirror apparatus. The abnormally distributed rotary prism thresholds were relatively higher than, yet correlated significantly with, those of the rotating mirror. The relative increase found with the prism in the rate of deterioration of acuity with an increase in angular velocity was attributed to the exclusive factor of the rate of repeated rotation of the eye.


The same apparatus is used as before. The mirror is rotated at angular velocities of 10° per second to 170° per second at the nodal point of the eye to be tested. The visual acuity decreased rapidly and markedly as the angular velocity was established by the following semi-empirical equation:

\[ Y = a + bx \]

where: 
- \( Y \) = size of critical detail in minutes
- \( a \) = predicted value of static visual acuity in minutes
- \( b \) = measure of dynamic acuity
- \( x \) = angular velocity in degrees per second

1958 Miller, J.W. STUDY OF VISUAL ACUITY DURING THE OCULAR PURSUIT OF MOVING TEST OBJECTS: II. EFFECTS OF DIRECTION OF MOVEMENT, RELATIVE MOTION AND ILLUMINATION


The manner in which visual acuity decreases is similar with angular velocity horizontally, vertically, or with rotation in a horizontal plane. The formula \( Y = a + bx \) describes all three movements. The higher the relative angular velocity, the greater the intensity of illumination must be in order to maintain a given visual acuity threshold.

1961 Lewich, K. Miller, J.W. THE PERCEPTION OF MOVEMENT RESISTANCE IN THE GANSEFIELD


See abstract under Illusions and Visual Perception: Night Myopia, Space Myopia, and Gansfeld.

1961 Schumann, W.P. VISUAL ACUITY AND OPTOKINESIC NYSTAGMUS


See abstract under Nystagmus.

1964 Burg, A. AN INVESTIGATION OF SOME RELATIONSHIPS BETWEEN DYNAMIC VISUAL ACUITY, STATIC VISUAL ACUITY AND DRIVING RECORD

XIX. VISUAL ACUITY - STATIC

1943 EANE, A. L.
CORRELATION OF DEFECTIVE VISUAL ACUITY AND POOR OCULAR MUSCLE BALANCE ON ABILITY TO SUCCEED IN FLYING TRAINING
See abstract under Ocular Muscle Balance.

1948 DEPARTMENT OF THE ARMY
STUDIES ON VISUAL ACUITY

1956 WHITE, W.J.
THE EFFECT OF GRAVITATIONAL STRESS UPON VISUAL ACUITY
See abstract under Illusions and Visual Perception: Gravitational and Vestibular Effects.

1957 RANKIN, C.R.
THE EFFECT OF HORIZON-LINE LUMINANCE GRADIENT UPON TARGET DETECTABILITY IN ITS VICINITY
See abstract under Flash Blindness, Clare and Radiation Effects.

1958 WHITE, W.J.
ACCELERATION AND VISION
See abstract under Illusions and Visual Perception: Gravitational and Vestibular Effects.

1960 LURIA, E.M.
VISUAL ACUITY UNDER RED VERSUS WHITE ILLUMINATION
See abstract under Dark Adaptation.

1960 WHITE, W.J.
VARIATIONS IN ABSOLUTE VISUAL THRESHOLDS DURING ACCELERATION STRESS
See abstract under Illusions and Visual Perception: Gravitational and Vestibular Effects.

1961 PICCO, L.D.
THE EFFECT OF TRANSIENT WEIGHTLESSNESS ON VISUAL ACUITY
See abstract under Illusions and Visual Perception: Gravitational and Vestibular Effect.

1961 WURFOLD, H.A.
THE OBJECTIVE MEASUREMENT OF VISUAL ACUITY: BY ARRESTING OPTOKINETIC NYSTAGMUS WITHOUT CHANGE IN ILLUMINATION
A definition and delineation of factors affecting visual acuity are given. Visual acuity is affected by inherent and external factors which to a great extent don’t significantly influence visual acuity in a clinical examination. The author cites several examples.
(a) Optimum pupil size for visual acuity is 2.6-4.0 mm, however, visual acuity is still accurate with pupil sizes up to 5.6 mm.
(b) The eye, and human being as a whole, are very adaptable to various prevailing conditions.
Good delineations are given of the following objective methods of
examining visual acuity.
(1) Evoking optokinetic nystagmus - dependable results though they didn’t consider theoretical treatment of resolutions.
(2) Arresting optokinetic nystagmus - these methods (based on an evaluation of visual acuity by reaction of the eye to changes in illumination) "do not seem to give trustworthy results".
(3) Galvanic skin response - very comparable to a subjective exam.
(4) Evoking oscillatory motion - same as (1).
An investigation was carried out to establish whether visual acuity could be casted by arresting nystagmus using the authors procedure. A mutual relationship between the decisive details of test figures was used in both subjective and objective techniques. A thorough delineation of the apparatus, testing procedure and results was presented. The results showed that the authors method is suitable; mutual independence between details.

1963 VANDERPLAS, J.N.

VISUAL CAPABILITIES OF PERFORMING RENDEZVOUS IN SPACE


This paper is a review of the detection, discrimination, recognition, identification, judgement, acquisition, homing and docking of space vehicles, pointing out the inadequacies of existing data (1963).

1963 WHITE, R.J.

VISION AND UNUSUAL GRAVITATIONAL FORCES


See abstract under Illusions and Visual Perception - Gravitational and Vestibular Effects.

1964 BUNG, A.

AN INVESTIGATION OF DYNAMIC RELATIONSHIPS BETWEEN DYNAMIC VISUAL ACUITY, DYNAMIC VISUAL ACUITY AND DRIVING RECORD


See abstract under Visual Acuity-Dynamic.

1966 BUNG, A.

VISUAL ACUITY AS MEASURED BY DYNAMIC AND STATIC TESTS: A CORRELATIVE EVALUATION


See abstract under Visual Acuity-Dynamic.

1966 DUNLIP, S.G.

VISUAL ACUITY MEASURED DURING PROLONGED WEIGHTLESSNESS


Tests of visual acuity were performed in connection with the long duration earth orbital flights of Gemini 5 and 7. A small testing device was used by the crew members on several occasions before, during and soon after the flights. No change in the visual acuity was detected.

1968 WHITCOMB, H.A.

THE MEASUREMENT OF VISUAL FUNCTION (SYMPOSIUM) PROCEEDINGS OF SPRING MEETING 1965


Several papers are included on the clinical and laboratory measurement of visual acuity.
Also see abstracts under Color Vision, Dark Adaptation, Depth Perception and Stereopsis, Ocular Muscles Balance, and Refractive Error and Refraction.

1968 DUNLIP, S.G.

EXPERIMENTS OF VISUAL ACUITY AND THE VISIBILITY OF MARKINGS ON THE GROUND IN LONG-DURATION EARTH-ORBITAL SPACE FLIGHT


See abstract under Space Flight, Including Reconnaissance and Surveillance.

1968 KONIGSMANN, L.

SOME EFFECTS OF X-AXIS VIBRATION OF VISUAL ACUITY


See abstract under Effects of Vibration.

1968 KUMA, S.M.

RELATIONSHIP BETWEEN STATIC AND DYNAMIC STERE-ACTIVITY


See abstract under Depth Perception and Stereopsis.
1954 COCHRAN, L.B. VARIATION IN HUMAN GRAVITY TOLERANCE DUE TO
Card, F.W.
Northworthoy, M.E.
1954.
See abstract under Illusions and Visual Perception: Gravitational
and Vestibular Effects.

1957 ADUS, H.W. HYSSTAGUS ELICITED BY HIGH INTENSITY SOUND
et al.
See abstract under Nystagmus.

1957 FOWLES, C. PILOT STUDIES OF SCOTOPIC SENSITIVITY TEST
Dimmick, F.L.
Sweeney, E.J.
See abstract under Dark Adaptation.

1958 MILLER, E.F. EFFECT OF BREATHING 100% OXYGEN AT ATMOSPHERIC
PRESSURE UPON THE VISUAL FIELD AND VISUAL ACUITY
Pensacola, Fla. Res. Proj. NN 12-01-11, Subtask 11, Rep. No. 1,
March 1958.
See abstract under Atmospheric Effects.

1958 BLACKWELL, N.R. DETECTION THRESHOLDS FOR POINT SOURCES IN THE
PERIPHERY - FINAL REPORT
Hildener, A.B.
2455, June 1958.
Two observers obtained visual detection thresholds for the foveal
center and for 32 locations in the peripheral retina, within a
radius of 12° from the fovea. The locations fell along 8 equally
spaced meridians of the visual field, at distances of 1, 2, 6, 8 and
12° from the fixation center. These measurements were made at such
of nine levels of background luminance, ranging from zero to 75 foot
lamberts. A total of 368,250 observations were made utilizing the
temporal forced-choice variant of the method of constant stimuli.
The target was a circle whose diameter subtended 1 minute of an arc;
the exposure duration was 0.01 second. The relationship between
threshold contrast and background luminance for the foveal and
peripheral locations was plotted showing discontinuities in the
periphery, these are said to represent the well-known rod-cone
"break".

1960 WHITE, U.J. VARIATIONS IN ABSOLUTE VISUAL THRESHOLDS
DURING ACCELERATION STRESS
9 Refs. Wright Air Dev. Div., Wright-Patterson AFB, Ohio. Proj.
See abstract under Illusions and Visual Perception: Gravitational
and Vestibular Effects.

1962 BEICHER, D.E. EXPOSURE OF MAN TO LOW INTENSITY MAGNETIC
FIELDS
See abstract under Flicker Fusion Frequency.
XXI. VISUAL STANDARDS

1916 COTTLE, G.P. NAVAL AVIATION PERSONNEL

Many people think the aviator must have some peculiar inherent quality of eyes by which he is able to fly. The beginning of naval aviation was 1910-1911. Physical requirements are given in the Manual for the Naval Manual U.S.N., 1914, Chapter 12, Paragraph 2113. These were:
1. Visual acuity shall be normal without glasses. Any error of refraction is rejected.
2. The candidates ability to estimate distance will be determined (method not given).
3. Color blindness for red, green or violet is a cause for rejection.

8. Color perception—Jennings yarn test cards
9. Muscle balance at 20 feet—stethoscope used, must be no more than 1" hyperphoria or 2" exophoria or exophoria
11. N.P.C. 11 cm at age 20; 13 cm at age 22; 15 cm at age 30
12. Ophthalmoscopy with gonioscopy.

1917 CONNOR, C.H. THE SPECIAL PHYSICAL EXAMINATION OF AVIATORS FOR THE UNITED STATES NAVY

The report states, "the most important part of the inquiry narrows down to the examination of the sense of equilibrium.

1918 MILITARY AERONAUTICS

1918 U.S. W protection and DEPARTMENT
AIR SERVICE MEDICAL


Pilots were classified into one of three altitudes at which they were apparently safe based on tests to determine their ability to sustain anoxia.

Also see abstracts under Atmospheric Effects, and Depth Perception and Stereopsis.

1918 LANGST
THE EFFICIENT SELECTION AND CARE OF FLYING OFFICERS

No Ref. Lancet, 1:190-191, 1918.

The paper gives a general treatment of the problem only. Useful quote, "... it must be remembered that, at present, these (standards) are mainly tentative and theoretical, and evolved for the most part by medical men who have no practical knowledge of aviation . . ."

1918 ANDERSON, H.C. AVIATION AND MEDICINE, AND THE SELECTION OF CANDIDATES FOR THE AIR SERVICE


Transactions of the first meeting of any medical society in Britain having talked medically about aviation are recorded.
1. Excess in smoking could lead to diplopia.
2. 
3. Heterophoria may cause bad landings (red and green lens test used to evaluate heterophoria).
4. The night blindness test is given only for night flying.
5. Stereoscopic vision "need hardly be tested".

The discussion afterwards was recorded:
(a) E. Clark said small errors were infinitely worse than large and obvious errors. Heterophoria should be a cause for rejection, especially exophoria.
(b) J. Galloway said vision tests must be standardized and the candidate must have a full visual field.
1918 Flack, M.

**Scientific Tests for the Selection of Pilots for the Air Force**


This paper seems to be based heavily on H.C. Anderson's paper to the Medical Society of London. It says, "... the candidate shall have accurate vision ... (w) must rule out concealed hypermetropia. A good color sense is also necessary." The tests are carried out at the British Aviation Candidates Board.

1919 Automotive Industries

**International Medical Requirements for Aerial Navigation**


Medical requirements are given for the examination of pilots drafted by the Aeronautical Commission of the Peace Conference in Paris. The eye examination consisted of:
1. The degree of visual acuity required must be compatible with the efficient performance of his duties.
2. No pilot can have more than 2 D of latent hypermetropia.
3. Muscle balance must be good and commensurate with refraction.
4. Each eye must have a good field of vision.
5. Color perception must be normal.
Each state may use its own methods at present. Re-examinations should be every six months. Each state may raise, but not lower these minimum requirements.

1920 U.S. War Department

**Aviation Medicine in the A.E.F.**


The entrance requirement for "phoria exclude about 1° of hyperphoria or 2° of exophoria at 5 meters." The report contains details of which instruments are used for color vision and stereo vision tests. Page 175 gives the effects of lowered oxygen tension on visual aspects. Page 176 gives graphs of the weakening of ocular muscles with various altitudes. Accommodation requirements are recorded: near point of accommodation at 20 years of age should be less than 110 mm, for 25 years of age less than 130 mm, for 30 years of age less than 150 mm. Quote from page 184, "... it seems that the converging power should never be less than double the diverging power at all distances."

1922 Tefft, L.E.

**Speed of Accommodation as a Practicable Test for Fliers**


An experiment was done with a tachistoscope to see whether speed of accommodation should be a test in the standards to fly. Sixty subjects were used and a relationship of results was made with visual acuity, depth perception, accommodation, power of convergence and divergence, and retinal sensitivity measured with Cobb's apparatus. At present the standards allow a leeway above or below the normal for each as determined by Duane.

1923 Beringer, C.

**The Eye in Aviation: Some Experiences in the Work of the Department of Ophthalmology, Medical Research Laboratory, Third Aviation Instruction Center, A.E.F., France**


The paper claims to be a complete bibliography; it is extensive anyway. Visual standards (1923) are given:
1. Extrinsic ocular muscles—"... it seems that the converging power should never be less than double the diverging power at all distances."
2. Accommodation—the near point of accommodation must not be greater than: 110 mm at age 20 (9.09 D); 130 mm at age 25 (7.69 D); 150 mm at age 30 (6.67 D).
3. Near point of convergence—"over 80 mm would seem cause for rejection."
4. Visual acuity—uncorrected 20/20 O.U. with no more than 2 D of latent hypermetropia would seem to be all right.

1923 Davis, W.R.

**The Development of Aviation Medicine**


The paper gives a general account of the early history of aviation. The first medical exams for flying in the U.S. were given in 1912; the first blanks and instructions for how to carry out the exam were issued in July, 1914. The first Flight Surgeon was appointed on September 5, 1917. An interesting quote on page 214, "... examining a flier's eyes ... does not call for a skilled ophthalmologist."

1923 British Journal of Ophthalmology

**Section of Ophthalmology: Discussion on Ophthalmology in Its Relation to the Navy, Army and Air Force**


See abstract under Ocular Muscle Balance.

1927 Lot, A.W.

**Disqualifying Eye Muscle Imbalances in Aviation**

112

See abstract under Ocular Muscle Balance.

1927 LANCET

MEDICAL REQUIREMENTS FOR FLYING AS LAID DOWN BY THE INTERNATIONAL COMMISSION FOR AIR NAVIGATION


Eye exam requirements for private pilots were 6/9 O.U. with correction if necessary. Ocular poise, visual fields, and color vision should be normal. Eye exam requirements for the crew of aircraft for public transport stated that "the candidate must not be completely deprived of the use of either eye and his pupillary reflexes must be normal." Vision must be compatible with efficient performance of his duties, i.e., 100% visual acuity 0.0. with no correction.

1929 IKSTADT, A.

PHYSICAL QUALIFICATIONS AND AERONAUTICAL ADAPTABILITY


The study was conducted to determine whether the variation in quality of visual attributes within the standards had any bearing on training failure rate. There was no correlation between depth perception, lateral ocular poise, hyperphoria, degree of difference of accommodation between the two eyes, anisometropia and the failure rate. Hence, "differences in physical findings considered bear no relation to students success of failure... the present standards are not too lax." Some visual parameters measured at this time were:
1. Depth perception: 0-25 mm satisfactory
2. Heterophoria: esophoria and exophoria distance and near (no quantitative data)
3. Hyperphoria: 0-0.75 A satisfactory
4. Accommodation: 0-2 D difference between cycs satisfactory
5. Anisometropia: (criteria for anisometropia not given).

1929 BENJAMIN, J.D.

ANALYSIS OF AVIATION PHYSICAL EXAMINATIONS


An analysis is given of individual causes of rejection for flying in the Navy during the 18 months prior to the report. The report shows that 20.6% of the candidates were rejected for inability to read 20/20. In all, 44% were rejected for eyes alone. Hence, eye defects are the greatest physical cause for rejection.

1929 STITT, E.R.

TRENDS IN MEDICAL AVIATION

No Refs. California and Western Medicine, 13:377-382, 1929.

On the advice of General Wilmer (eminent ophthalmologist) 1/2" hyperphoria limit is now raised to 3/4" (1929). Quote, "the specialists at Pensacola have failed to note any superiority in student pilots who just pass the various eye tests with those who have little or no defects."

1930 HERTZOG, F.C.

THE EYE EXAMINATION


Between 1920-1930, 78% of all medical rejections were for eye defects. This paper is really an account of the authors personal eye exam routine with notes pertaining to increasing the reliability of the results.

1930 THorne, F.R.

A REVIEW OF OCULAR MUSCLE IMBALANCE (WITH REPORT OF TWO-HUNDRED AND FORTY-FOUR CASES)

5 Refs. Military Medicine, 66:175-205, 1930.

See abstract under Ocular Muscle Balance.

1930 COOPER, H.J.

THE RELATIONSHIP BETWEEN PHYSICAL DEFICIENCIES AND DECREASED PERFORMANCE


The British found during World War I that their first method of sending anyone who passed the recruiting examination, or who was "a washout" from other branches of the service, to the air force resulted disastrously. Results in the first year indicated that 60% of the pilots killed at death as a result of physical defects. By a subsequent demand for higher physical standards the initial 60% was reduced to 12% in two years. The Air Commerce Act of 1926 placed standards for civil aeronautics under the administration of the Secretary of Commerce as "Air Commerce Regulations". "Physical Standards for Airplane Pilots" elaborates on physical requirements and methods of procedure for medical examination. Military regulation and standards for flying are much more rigid than civil ones. The International Commission for Air Navigation, formed in 1919, represents 26 foreign countries and its regulations govern international air navigation. Though the U.S. had not ratified the I.C.A.N. convention their civil aeronautic requirements adhered closely to them. Regarding regulations made at this time, a delineation of the visual standards for flying personnel are given. "Bad landings are frequently due to ocular muscle imbalance." Wilmer reports (Aviation Medicine in the A.E.T., Document No. 1004, Government Printing Office, Washington, D.C.) that Clements of England found 84% of officers turned down for bad landings were successfully treated by visual training techniques. Trained pilots should have at least 2 D of accommodation. The Department of Commerce considers color vision, field of vision, diplopia, and
muscle tests as part of the routine visual examination. A delineation of ophthalmic dispensing of goggles with and without prescription is made. General conclusion of the article: "Physical departures from the normal correlate well with decreased performance."

1931 - ARMY MEDICAL BULLETIN - THE SELECTION OF THE AVIATOR

The report describes the methods of measuring the visual parameters in full.

Also see abstract under Ocular Muscle Balance.

1931 - BEERS, C. - PRESENT OPHTHALMOLOGIC STANDARDS FOR COMMERCIAL AVIATION IN THE UNITED STATES

See abstract under Depth Perception and Stereopsis.

1931 - CHASE, J. S. - EYES IN AVIATION

A general introduction to eye examinations for aviation is given. The paper insinuates that W.H. Wilmer had much to do with forming the original standards. The following standards are given:
Department of Commerce, Transport and Limited Commercial License 1926—20/20 O.U. separately without glasses, normal muscle balance, visual fields, color vision, and depth perception. Student and private pilot—20/50 O.U. corrected to 20/20, providing the depth perception result is not over 30 mm.

Army and Navy additional requirements—the candidate is disqualified if a latent error (spherical or cylindrical) of over 1 D with homatropine is found. The angle of convergence and the muscle balance at 30 cm is measured.

One eyed pilots are not accepted because there are so many applicants for each position with 2 eyes.

1931 - WEDELHAGEN, H. V. - PHYSICAL EXAMINATION OF AVIATORS

Useful quotes, "20/20 or 100% sharpness in sight required," and "the ocular musculature must function normally."
disqualifies if associated with greater than 1° hyperopia.
11. Central color vision with Jennings self-recording test
12. Field of vision for form and color with Scheieigcr hand perimeter
13. Refraction greater than 1 DS with cycloplegic disqualifies, greater than 1/2 DC with cycloplegic disqualifies

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1935 MASSENBURG, N.C. SOME INTERESTING PSYCHOLOGICAL FACTORS IN THE SELECTION OF MILITARY AVIATORS

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1936 WHITE, M.B. TESTS FOR COLOR-BLINDNESS

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1938 SCHWALTER, A. THE EVALUATION OF ORTHOPTIC TRAINING FOR AVIATION

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1939 ARMSTRONG, H.G. PRINCIPLES AND PRACTICE OF AVIATION MEDICINE

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1939 MASSENBURG, N.C. THE SELECTION OF THE TRAINER FOR MILITARY AVIATION

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1940 U.S. WAR DEPARTMENT STANDARDS OF PHYSICAL EXAMINATION FOR FLYING

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1942 LILJENCRANTZ, E. PROBLEMS IN THE SELECTION OF AVIATORS

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1942 WHITE, M.B. A STUDY OF THE VALUE OF THE PSEUDO-ISOCHROMATIC COLOR VISION TEST IN THE SELECTION OF THE MILITARY PILOT
1942 Bahn, C.A. Ophthalmic Requirements of the Military Service

A refraction is carried out with cycloplegic. In the Army each eye must have an error less than +1.5 DS or -0.50 DC. In the Navy each eye must have an error less than +0.75 DS or -0.50 DC. No dark adaptation tests are given.

1943 Bahn, C.A. Ophthalmic Requirements of the Military Services. Revision February 1, 1943

A change in requirements from the above paper (1942) are given:
1. Different standard for power of convergence.
2. Power of divergence further defined.
3. Red lens test further defined.

1944 Bahn, C.A. Ophthalmic Requirements of the Military Services: Changes from February 1, 1943 to January 1, 1944

The requirements are unchanged from 1943 except for those pertaining to the Army Air Corps (see above paper). Some are slightly relaxed for applicants for air crew training.

1945 Bahn, C.A. Ophthalmic Requirements of the Military Services. Changes from January 1, 1944 to January 1, 1945

The differences in the requirements from 1944 are:
1. Visual acuity is tested at 50 cm.
2. Esophoria does not have to be less than +4 when associated with prism divergence less than 40.
3. The power of convergence must not exceed the P.D.
4. The table or required accommodative status is given.
5. The table of required field of view is given.

1946 Royal Canadian Air Force Visual Factors in Aircrew Selection

See abstract under Ocular Muscle Balance.

1945 Scobee, E.G. A Comparison of Tests for Heterophoria: Variations in the Screen-Maddox Rod Test Due to Ocular Dominance, Red Color and Screening

The report shows that esophoria is induced both at near and far with a Maddox rod whether it is white or red. However, a white Maddox rod induces about 0.25° less esophoria at 20 feet. It is also shown that no significant difference is found in the results whether the Maddox rod is placed before the dominant or non-dominant eye. He recommended that the standards should be changed to accommodate the above.

Also see abstract under Ocular Muscle Balance.

1945 Scobee, E.G. An Analysis of the Ophthalmic Portion C. "64" Examination - (2) Muscle Balance - a Summary of Suggested Changes

See abstract under Ocular Muscle Balance.

1946 NRC Committee on Selection A Study of Visual and Cardio-Vascular Standards and Training of Aircraft in Relation to Success in Flight Training Pilots

No significant relationship was found between visual cardio-vascular defects investigated and criterion measures of proficiency in the flight training course. The visual factors included acuity, depth perception and accommodation. Four samples of R.A.F. cadets in training at 4 centers in the U.S. served as the subjects. The R.A.F. standards were lower than those of the U.S. services—hence it appears that the Army and Navy standards are unnecessarily stringent.

1947 Lyons, E.G. Analysis of the Causes of Disqualification of 164,687 Applicants Rejected for Aviation Training

See abstract under Physiopathology.
Two hundred and fifty Naval Aviators who had returned from combat or operational tours of duty were given complete eye exams and other tests. The subjects ages ranged between 20-30. An Orthorater was used in testing. Extensive correlations were made between the tests carried out. No significant relationship between for lateral phoria and depth perception was found when measured with the Orthorater. The four tests of depth perception used had a low degree of correlation between them. The 30 mm limit on the Howard-Dolman test was failed by 12.4% of the subjects. Useful quote, "the visual standards for Naval Aviation had been established some 20 years previously (about 1924) upon an arbitrary basis, using the best ophthalmological judgement at the time as to what constituted normal visual performance. Unfortunately for science, too few persons with defective vision are willing to attempt the flight training without wearing glasses which correct their vision to normal." The study supposes that important visual factors would cluster around the same level, whereas others would show a wide distribution, e.g. depth perception has a wide distribution.

Also see abstract under Ocular Muscle Balance.

Also see abstract under Ocular Muscle Balance.

Two hundred subjects were divided into 4 groups:

Group A—containing 80 subjects with 20/20 O.U. or better; they had very good stereopsis and low refractive error.

Group B—containing 40 subjects with 20/50 or worse uncorrected with 20/20 corrected, high stereopsis, refractive error under 3.00 DS or 2.00 DC also present.

Group C—containing 40 subjects with 20/100 or worse O.U. uncorrected with 20/50 corrected; stereopsis of 10 cm at 6 meters and refractive error of about 4.00 D also present.

Group D—containing 40 subjects sub-grouped into 3 groups, all basically monocular.

A definite relationship was shown between visual efficiency and flight performance. The failure rate of a 20 hour private flight training course was as follows: A) 13% B) 21% C) 30% and D) 49%. However, the study showed that students with defective visual acuity were less motivated to fly than those with unimpaired vision. It seems that those in groups C and D may have been influenced by comments made to them saying they were endangering themselves in undertaking flight training. Page 341: 32% of the subjects in C and 27% in D attained scores above the average in A. No accidents were reported in the whole study of 8,000 hours.
The physical requirements of military and commercial aviation are "rigid and are scrupulously maintained." The purpose of standards is to reduce to a minimum the number of persons who may become incapacitated later. Physical standards for pilots of all types of aircraft and of all types of flying are set by the Armed Forces and Dept. of Commerce, and all pilots must have a physical exam every 6 months. There are four visual elements of concern in the exam:

1. Acuteness of vision
2. Judging distance
3. Efficiency of the extraocular muscles
4. Color discrimination

Near vision and amplitude of accommodation are also considered. The Howard-Dolman apparatus is used for depth perception. The relationship between accommodation and convergence is assumed to be 1:1. Regarding color testing, the military follows an outline by Cooley and Crow (Cooley, E.E., and H.C. Crow, Color Vision, Army Tech. Bull., No. 34, 1-31, January 1936) which delineates color vision and defects based on the Edrldge-Green theory. The Ishihara plates and the Holmgren Yarn Test are routinely used, the latter claimed to be the most efficient, and thus subsequently used when doubt arises with the other tests. The visual standards were adopted when flying was in its infancy, and experience was minimal. Consequently, they are more or less arbitrary. Scientifically, the adopted limits have never been justified. Many standards were derived from statistical means, and people with greater error have never been allowed to demonstrate their ability. However, relaxation of the visual standards is not warranted because, "the basis on which they are founded are sound."
Ho justification for present UHAF standards of minimum accommodation was found and an absolute minimum of 4-3 D is suggested. The author agrees with Scobee in that altitude has no significant effect on the 'phorias.

Also see abstract under Depth Perception and Stereopsis.