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Technical Report No. 4

THE VISUAL REALM IN SPACE

Study of Visual Perception
in Humans and Animals

John Lott Brown

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THE VISUAL REALM IN SPACE

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INTRODUCTION

Man has an important role in the exploration of space. It is probable that for his size, mass, and energy requirement he can handle a broader range of situations more effectively and with more flexibility than any automatic equipment which might be designed. He will be able to make decisions in relatively unique situations, many of which are beyond the ability of even the most elaborately programmed automatic devices. He will not be operating in his own familiar terrestrial environment, however. His sensory input channels must therefore be evaluated in relation to the new situations which he may encounter and in relation to the environmental differences which may be anticipated. It is reasonable to suppose that limitations which exist in any sensory dimension on Earth will also exist in space. It is also possible that additional limitations may be imposed.

I will concern myself in this presentation exclusively with the visual dimension. I would first like to review some of the characteristics of the visual sensing system and comment on their significance for man on a space mission. I will then review some of the unique conditions which may be encountered in space flight, particularly those which can be expected to influence vision. Some comments will be made on the nature of the visual environment in space, and, finally, some of the visual functions which may be of particular importance will be discussed.

THE NATURE OF THE VISUAL SYSTEM

The human eye is an amazingly sensitive device. Light rays which enter the cornea and pass through the various intraocular media excite receptors on the retina. Light must actually pass through a number of layers of nerve fibers and nerve cells as well as some vascular tissue before reaching the receptors. At the receptor layer, it has been demonstrated that only a very few, perhaps four or five, quanta of light energy are necessary for the conscious detection of light (5). The response varies with wave length and the nature of the spectral response varies with the condition of adaptation of the eye (5). This is illustrated in Figure 1. There will be ample illumination, at least at times, on the moon and on Mars for visual observation. The curves presented in Figure 1 are slightly misleading in that they imply equivalent maximum sensitivity for both the daylight, photopic process, and the low-luminance, scotopic process. Actually, the eye becomes more sensitive to light as it adapts to the lower luminance levels with an accompanying shift in peak sensitivity to a shorter wave length. The relation is better illustrated in Figure 2 where relative energy required for stimulation is shown for both photopic and scotopic vision (18).

The transition from photopic to scotopic vision may present problems for the space traveler. Although the eye can adapt to an increase in illumination level within its functional range fairly quickly, a relatively long time is required for adaptation to very low luminance levels. Adaptation to a higher level requires no more than three to five minutes. Adaptation to low luminances may require thirty minutes or more (6). The dark adaptation process is illustrated in Figure 3 (1). An important characteristic of the data presented in Figure 3 is the fact that the range of change in sensitivity shows an important relation to the area of the test spot with which sensitivity is measured. An experiment of the sort illustrated here demonstrates that the tremendous gain, as much as 1,000,000:1 or more, in visual sensitivity with dark adaptation cannot be explained purely in terms of an increase in the concentration of photosensitive material during dark adaptation. The gain in sensitivity is also a result of a change in neural organization. The eye becomes able to summate energy over a larger area. This is illustrated by measurements of the "receptive field" of a single fiber of the optic nerve (4). In the light adapted eye a fairly large region of the retina, when stimulated, influences activity in a single fiber (Figure 4). The influence may be either excitation or inhibition, however. In a central area light stimulation may cause increased activity in the fiber, in an annular region around this central region light stimulation may inhibit activity in the fiber. With dark adaptation the excitatory region is enlarged and the inhibitory region drops out. Accompanying this change there appears to be an increased ability of the retina to summate over its area the stimulating effect of light energy which reaches the retina. A corollary of the increasing sensitivity with dark adaptation is a gross reduction in spatial resolution capacity at low luminances. Increased sensitivity afforded by increased spatial summation is accompanied by decreased spatial resolution capacity (46).

Spatial resolution will be an important function for the space traveler.. It is of importance to know what the limiting resolution of the eye is and to know how this varies with changing conditions. In general, spatial resolution will increase with increasing luminance and with increasing contrast between objects to be discriminated and their backgrounds (16, 46). The relation between visual acuity and luminance is illustrated in Figure 5. Visual acuity is defined as the reciprocal of the minimum resolvable visual angle in minutes of arc. It is important to note that there are various kinds of visual acuity, however. Visual acuity for resolution of the minimum separation between two points or elements of detail in a visual array is not nearly as fine as visual acuity for the resolution of a single dark line element against a bright field.(46). It is meaningless to speak of visual acuity for a point source of light because its size is not a limiting factor. Stars are essentially point sources of light but are detectable when their energy level is sufficient to stimulate the retina. The retinal image of a point source will always have a finite size by reason of the optical properties of the eye (47). Visual acuity for elements of detail in a complex visual scene is of the order of 1, that is, separations between elements of detail which subtend a visual angle of 1 minute of arc can be discriminated. A dark line against a bright field can be discriminated when its thickness subtends less than a half-second of arc at the eye (46). Dark spots against a light background as small as 15 to 30 seconds of arc can be detected. The length of a dimension in feet which will subtend 1 minute of arc at the eye of an observer is equal to one and one-half times the distance of the observer in miles (9). Thus, at an elevation of 100 miles over the surface of the earth or the moon, minimum resolvable elements of detail in a complex pattern must be 150 feet in length. On the other hand, a single dark line of less than two feet in width may be discriminated at the same distance if it is sufficiently long and affords sufficient contrast with its background. Astronauts who have participated in orbital flights have observed that tentative identification of many objects on the ground can be made on the basis of what the astronaut knows to be there or on the basis of inference (55). For example, a discontinuity along the extent of a clearly visible river may quite correctly be interpreted as a bridge although out of context its identification would be impossible.

The character of the receptive field of a single cell in the light-adapted eye is an important factor in spatial resolution. The nature of its function is illustrated in Figure 6 (19). Stimulation of the center of its receptive field on the retina gives rise to much activity. Stimulation in an annular ring around its center suppresses activity. Stimulation of a larger area tends to increase activity but the change in relation to the background level may be very slight. This combination of excitation and inhibition dependent upon spatial region stimulated provides a basis for peaking of contours in the retinal image. It is thus useful for the enhancement of visual detail. This is illustrated in Figure 7. Vertical stripes of increasing darkness appear non-uniform from left to right. The edge of a given stripe near its adjacent dark stripe appears lighter than its opposite edge. The fact that this is a property of the eye may be illustrated by covering the adjacent areas on both sides of part of one of the stripes with dark paper. The apparent gradient is eliminated (17).

If our attention is transferred from single cells and fibers in the region of the retina to single cells in the visual cortex, we find a change in the nature of retinal stimulation which is optimum for excitation and inhibition of these cortical cells. Optimum retinal stimulation is found to be organized along line elements for excitation of many cortical cells. This is illustrated in Figure 8 from an experiment reported by Hubel and Wiesel (33). Some cells respond to stimulation along a line of specific orientation in a certain part of the retina. Other cells appear to be sensitive to orientation of a line but less dependent upon the specific position of the line on the retina. This is illustrated in Figure 9, again from the work of Hubel and Wiesel (33). A possible effect of this kind of organization within the visual system is illustrated by Figure 10. If one fixes the center of the radial line pattern for a period of approximately 10 seconds and then observes a completely plain white field, an afterimage pattern of annular rings is seen. It is as if the cortical cells which mediate discrimination of the radial line pattern have been "fatigued", and stimulation by a plain field permits the accentuated response of other cells responsive to orthogonal stimulation. The result is a series of concentric circles.

The temporal resolution capacity of the eye is of concern in relation to the ability to perceive information in a rapidly changing visual field. This may be of practical importance in the relatively simple case where information is transmitted via a flashing light. Temporal response characteristics of the human eye are illustrated in Figure 11 (23). It is evident that the response extends to higher frequency at higher luminance levels. The ability of the retina to summate energy in time as well as over area changes with illumination and level of adaptation, although the relation is complex (14). Part of the increased sensitivity of the dark-adapted eye is attributable to increased temporal summation capacity. This is, of course, accompanied by a decrease in temporal resolution.

The ability to perceive colors depends upon the presence of three photosensitive substances within the retina having different spectral absorption characteristics (40). Color discrimination also depends on some relatively elaborate data processing within the nervous system (25). It has been demonstrated that certain cells of the retina central to the photoreceptors themselves respond differentially dependent upon the wavelength of stimulation. Some wavelengths may excite these cells and others may inhibit their response. This is illustrated in Figure 12 (52). In Figure 13 are shown the records of a cell which is inhibited by a green light and excited by a red light (24). There is a burst of activity from this cell when the green light is extinguished. It is

as if extinction of the green light has the same effect on the cell as illumination of the red light. Response of the cell is greatest when the eye is stimulated by a red light, immediately following illumination by a green light. It can be demonstrated that the extinction of a green light may give rise to sensations similar to those which occur when the eye is stimulated by the red light. If one stares fixedly at the center of a pattern consisting of a red and a green rectangle for approximately 10 seconds and then observes a completely uniform white field, the region in which the green pattern was observed will appear reddish and the region in which the red pattern was observed will appear greenish. A similar effect may be observed in a yellow and blue pattern. These successive contrast effects and other simultaneous contrast effects influence interpretations of the visual world.
It has been suggested by some astronomers that the apparent coloration of the details of the Martian surface may be a result of such color contrast effects (3, 28, 36, 37). It is therefore dangerous to interpret them as indicative of a specific surface condition if they may be artifacts of the visual process.

EFFECTS OF SPACE FLIGHT ON VISION

It has been suggested that the nature of the limitations on the visual process which are inherent in the visual system itself will be the same in space as on earth. This notion should perhaps be qualified. Limitations which exist on Earth will undoubtedly exist in space, but additional limitations may be imposed by conditions which are unique to space flight. One element of concern is the gravity environment.

In launching a space mission it is necessary to employ accelerations which impose higher gravitational forces on the occupants of a space vehicle (7). When the orientation of these forces is such as to interfere with the circulation to the eye and brain, there may be a blackout of vision and other symptoms. Studies have indicated that by so positioning a pilot that the line of action of acceleration forces is transverse to the long axis of the body, it is possible to avoid blackout. Other visual effects may occur nonetheless. These problems have been studied extensively on large centrifuges which permit the exposure of human subjects to high acceleration forces (10). The Navy Centrifuge System at the Acceleration Laboratory in Johnsville, Pennsylvania, is illustrated in Figure 14. This centrifuge has been instrumented for closed loop operations such that a pilot may perform the control operations necessary for a specific mission and the acceleration forces imposed on him be determined by his control manipulations. A number of experiments have been performed on this device to determine the mechanical limitations imposed on the pilot by acceleration forces (8). Some studies have also been performed to determine purely visual effects. One of these is illustrated in Figure 15 (15). The time required for a subject to make a motor response to a visual signal is shown to increase with increased level of acceleration. It is also clear that the reaction time is influenced to an even greater extent by the luminance level of the visual signal. By using sufficiently bright illumination, relatively short reaction times can be obtained even at levels of acceleration near those which will cause blackout when acting along the long axis of the body. Dr. Joseph White and his colleagues, working at the Wright Air Development Center of the Air Force, have studied a variety of acceleration effects on vision (53). Figure 16 illustrates the reduction in visual acuity with increased acceleration up to 8 G units. There appears to be little difference in the effect on visual acuity for transverse and positive acceleration orientations. White has suggested that the effect on visual acuity may result from deformation of the optical system rather than impairment in the circulatory system. As in the case of reaction time, it can be shown that influences of acceleration on visual acuity, measured indirectly in terms of errors in reading an instrument, may be ameliorated by increasing the luminance level. This is illustrated in Figure 17, again from the work of White (54). High acceleration levels will be of relatively short duration, and barring accident they will not be so high that they need be a major concern as an impediment to space travel.

Possibly even greater concern has been expressed over the effects which the zero gravity environment of outer space in orbit or in interplanetary flights may have on visual processes. The exact basis for concern has not been well stated in all cases, but several experiments have been performed to assess possible changes in visual acuity and other visual discriminations in the zero gravity condition. Slight changes have been measured both in the direction of decrease and increase (45, 54). In an extensive experiment performed by astronauts in orbital flight (26) no significant difference was observed as contrasted with pre- and post-flight tests made on the ground. It is doubtful that zero gravity, at least for relatively short durations, has any influence on visual acuity. There has been greater concern with the possibility that mechanisms that control eye movement might be influenced by the absence of gravity. If coordination of eye movements is disrupted even slightly, the effect on perception and various judgments of distance or motion might be a handicap to the space traveler. Efforts to measure visual functions such as accommodation and phorias will be made in subsequent missions.

It is probable that motor systems adapt reasonably quickly to the absence of gravity cues. Astronauts have observed that eye-hand coordination is unimpaired under zero gravity. Even tactile approximation with the eyes closed appears to be about as good in a zero gravity condition as it is on the surface of the earth (55). There seems to be no tendency to overshoot or underreach which is associated with the absence of weighting of the limbs by a gravitational field.

The visual process is known to be quite sensitive to the respiratory environment. Reduction in the partial pressure of oxygen of the air breathed will cause measurable visual effects at altitudes as low as 5,000 feet. Changes are quite striking between altitudes of 15,000 and 20,000 feet. An illustration of this is presented in Figure 18 (42). Dark adaptation curves are presented for subjects breathing oxygen mixtures equivalent to the altitudes indicated. It is clear that the final threshold level in the dark-adapted eye is elevated considerably at the higher altitudes. Quick recovery from the highest altitude is demonstrated when subjects are permitted to breathe 100 percent oxygen. The astronaut will carry his atmosphere with him and he will be provided with an appropriate mixture to sustain him adequately. Any possible source of contamination may cause difficulty, however (38). The effects of reduced oxygen pressure are compared with those of cigarette smoking in Figure 19. It is shown that smoking two or three cigarettes causes an elevation in threshold equivalent to that caused by an increase in altitude of only 7500 feet (41). The effect of cigarette smoking may be explained in terms of the binding of hemoglobin by carbon monoxide inhaled with the smoke. Another possible basis of explanation is the vaso-constrictive effect of nicotine which may influence retinal circulation.

On some space missions a 100 percent oxygen environment has been employed at a pressure greater than the partial pressure of oxygen at sea level. Oxygen is known to be toxic and 100 percent oxygen at sea level will probably result in death in little more than 70 hours. Lesser effects which might be reflected by changes in visual function have therefore been considered a possibility with slight increases in the pressure of oxygen over the normal level. This possibility has been studied extensively with a variety of visual tests for increased partial pressures of oxygen up to that represented by 100 percent oxygen at sea level pressure with exposures for 24 hours (27). No effects on visual processes were observed.

Ionizing radiation is probably not a serious problem in relation to vision in space travel. At high levels, its effect on other than the visual system will be of most importance, and at low levels it probably will not cause serious difficulty. It has been demonstrated that exposure to ionizing radiation can cause cataract. It may also reduce visual sensitivity by direct or indirect action in bleaching the photosensitive substance of the eye (39).

An artificial restriction on the visual environment in space may be imposed by the necessity that astronauts wear a protective helmet with a transparent window. Visual field may be restricted by such a device along with the illumination, as this is restricted by the transmittance of the visor. Helmets may thus impose some limitations on vision for the space traveler but it is reasonable to assume that with continuing development of equipment these limitations will be reduced or eliminated.

THE VISUAL ENVIRONMENT OF SPACE

With his departure from the Earth's atmosphere, the space traveler will come into an entirely new visual environment. The atmosphere of Earth absorbs approximately 30 percent of the sun's radiation (48). The radiant energy level from the sun will thus be higher outside the atmosphere to this extent. Light scattering which occurs within the atmosphere will be absent and the uniform illumination provided by the daylight sky on the Earth's surface will not be seen. Stars and other objects will be seen against a darker background than that of the sky at night by reason of the absence of light scattering. Contrasts between illuminated areas and non-illuminated areas or the void of space will be much higher than those usually encountered on the surface of the Earth. This will be true on the surface of the moon as well as in space, by reason of the absence of any significant atmosphere around the moon (48, 50). The hazard to be encountered by looking directly at the sun will be increased over that which exists within the Earth's atmosphere. Whereas on the Earth's surface, injury to the retina may occur after gazing directly at the sun for a little less than one minute, the time will be 10 to 15 seconds outside the Earth's atmosphere (13, 48). Stars will no longer twinkle, and the colors of the sun and the stars will probably be more whitish in the absence of scattering of blue rays by an atmosphere. Solar illuminance will be nearly 14,000 foot candles, while background sky illumination will be an order of magnitude lower than that of the dark sky on a moonless night. Background illumination in the sky of space will be comprised of starlight, zodiacal light and galactic light. Beyond the distance of Jupiter from the Sun, the contribution of zodiacal light will be greatly reduced (48). A substantial contribution of light in the region of the Earth will be reflected from the Earth itself, 36 percent of solar light which falls on that body. This is substantially more than the light reflected from the moon (albedo .17 to .14). In the region of Venus, solar illumination will be approximately twice that in the region of the earth and the hazards of retinal exposure will be increased commensurately. In the vicinity of Mars, solar luminance will be less than half that at the Earth and in the region of Jupiter it will be reduced to less than 1/20 of the value which prevails in the region of Earth. The ideal range of illumination from the standpoint of human vision may fall somewhere between one hundred million kilometers on either side of the Earth's orbital distance. Stughold has referred to this region as a euphotic belt (48). It is in this region that life as we know it is most favored; gaseous oxygen and liquid water may be present.

Even at the mean distance of Pluto from the sun the illuminance provided will be sufficient for reading and for photopic vision in which colors may be discriminated. Insufficient illumination for photopic vision will exist at a distance from the sun about three times the distance of Pluto (about eighteen billion kilometers).

The visual realm on the surface of the moon is of particular interest at the present time (22, 50). The illumination level will be approximately 30 percent higher than that on the surface of the earth. The absence of atmosphere with its attendant light scattering will present a world of striking contrasts in illumination without the veil of sky illumination to fill in shadows. Shadows will not be completely dark where surface irregularities provide scattering and back illumination. The low reflectance of the moon's surface will limit the amount of back reflection which occurs, however. The result for an explorer on the moon's surface may be likened to the situation where someone is searching a crowded storage room with the aid of illumination from a single open bulb. Shadows will provide a striking element of the appearance and the overall appearance will vary greatly with any change in the direction of view of an observer with respect to the location of the light source. The presence of highly reflecting surfaces needed for thermal regulation of space vehicles and moon surface dwellings will present periodic exposures to very high luminance levels. This effect coupled with the darkness of shadows will render vision difficult. The problem of moving about on the surface under one's own power will be complicated both by the visual conditions and by the relatively low gravity of the moon (.167 Earth gravity). The surface of the moon for the most part will be porous material. This has been inferred by the change in reflected light with angle of incidence of the sun's illumination as this is measured from the surface of the earth (30). The nature of changes of light reflected from the moon appear to require that its surface be of some porous material. There is no evidence of any sharp selectivity in spectral reflectance but there does appear to be a gradual increase in level of reflection with increase in wavelength of the illumination light (22).

High illumination levels reflected from metallic surfaces as well as those seen when looking directly at the sun will present two problems. In the first place, they will cause light adaptation of the eye, thus reducing its ability to discern detail in the darker shadows. In the second place, they present a threat of retinal injury. The nature of these problems is illustrated in Figure 20 (11). As an adapting flash increases in its total energy, the time required for the eye to recover sufficiently to view visual detail illuminated at a much lower level increases. The increase occurs at increasing rate up to a point, probably representing depletion of photosensitive materials, where the curves oppear to level out. Somewhere beyond this energy level there will be irreversible injury resulting from retinal burning. The eye can recover from the adapting effect as this is represented by adapting flash energies up to the plateau of the curves. Retinal burns influence vision permanently, and if located in the fovea are extremely serious in their effect.

THE VISUAL TASKS OF THE SPACE EXPLORER

The visual requirements of an astronaut will fall in several categories (2, 9, 12, 34, 35, 43). The first of these is related to the task of controlling his vehicle and monitoring its position and attitude in space. During many stages of space flight this will be accomplished primarily by visual reference to flight instruments. Outside visual reference through portholes or a periscope will also be of importance (49). Outside reference may be to the surface of the earth, the moon or some other planet; to the stars; or to other space vehicles. It has been demonstrated that rendezvous and docking with two space vehicles can be accomplished by direct visual reference when appropriate controls are provided (21, 51). The control of a landing may also be effected by direct visual reference and laboratory studies of this possibility continue to compare the efficiency of direct visual control with that of automatic procedures.

The second category of visual tasks relates to the possibility of reconnaissance of a planet's surface from a space vehicle. This function will be limited by the visual acuity of the unaided eye. Where objects on the surface may be familiar, it will be possible to make identifications with minimal visual informaiton (43, 44, 49). On a completely unknown planet the problem will be far more difficult, however.

The judgment of size, when the nature of the object viewed is unknown, is extremely difficult. Photographs of the surface of the moon illustrate that it has a very similar appearance in terms of the distribution of visual angles which represent diameters of craters over a large range of distances. There is, thus, a range of crater sizes such that the visual pattern may look very similar from relatively near and far vantage points. Assistance in evaluating the nature of an unfamiliar surface may be obtained by the use of flares jettisoned from a space vehicle and the changing shadow patterns which result from flare illumination (12).

The detection of other space vehicles or objects in space may represent an important visual task for an astronaut. Detection of objects in space will not be limited by the resolution capacity of the eye but only by the amount of light reflected from the object to the eye. The task will be one of light detection rather than of spatial resolution. The largest problem in detection will be in localizing the region of space in which to scan for an object. Some familiarity with star patterns so that an anomalous object may be detected could conceivably be of value. It has been demonstrated experimentally that such detection will be extremely difficult, nonetheless (43). Another source of concern for detection is related to the relative motion of the object to be detected with respect to that of the vehicle which carries the observer. Times during which detections may be made for two vehicles which orbit the same planet or moon may be very limited.

Astronomical observations may be made from a space vehicle. The absence of an atmosphere will be helpful but the transmission characteristics of the window in the space vehicle may present some limitations. With the aid of a telescope, if a space vehicle carrying the instrument is sufficiently large, rather important observations can be made. Stabilization of the platform of the telescope may present a problem if human occupants of the space vehicle are moving about freely. In general, observations outside a space vehicle will be complicated, in many instances, by the lack of familiarity of the observer with the actual size of objects observed or with the nature of the terrain when a surface is observed. High contrast between points of illumination and background will result in an apparent change in size and shape of the source of illumination (29).

Inside a spacecraft, other problems may arise (12). These relate to the orientation of the astronaut with respect to his vehicle in the absence of gravity. The orbital flights which have been made to date suggest that this problem will not be a serious one. Its seriousness may increase, however, when larger vehicles are employed in which movements of much greater extent, involving the whole body, may be made. The absence of a gravitational vertical in this situation may be more serious than one in which the astronaut's position is relatively fixed in relation to his vehicle and instrument displays and controls within the vehicle. It has been suggested that it may be desirable to select arbitrarily some surface which shall be the "floor" and to construct interior spaces in the fashion similar to those with which we have become familiar on Earth (31). Such design may be less efficient than another which could conceivably cause greater confusion to an astronaut. Another suggestion has been that the vehicle be rotated to create an artificial gravity in the form of centrifugal force. In this instance, other problems may arise. For the length of rotational axis which would be practical, angular accelerations which will produce a substantial gravitational component will be relatively high and could cause difficulty by reason of their stimulation of the labyrinthine mechanisms of the inner ear.(12, 20). It seems most probable at present that the problems associated with zero gravity would be of less concern than those associated with rotation of a vehicle for creation of an artificial gravity, at least for missions of relatively short duration.

CONCLUSION

The characteristics of the human visual process have been reviewed briefly. It would appaar that these characteristics will remain relatively unchanged in space flight except under abnormal and emergency conditions at excessively high acceleration or low oxygen. The problem confronting the use of the sense of vision in space for an astronaut will be primarily the lack of familiarity with the space environment. In the region of Earth there will be ample light, but there will be excessively high contrasts and large ranges of illumination with which we are relatively unfamiliar on the surface of the Earth. The lack of scattering by an atmosphere will present additional problems. It is probable, nonetheless, that an astronaut will be able to adjust to conditions which prevail in space. With increased experience and the development of equipment to assist him, it is reasonable to predict that the role of the human explorer in space will be a significant one and much of what he accomplishes will depend upon his use of vision.

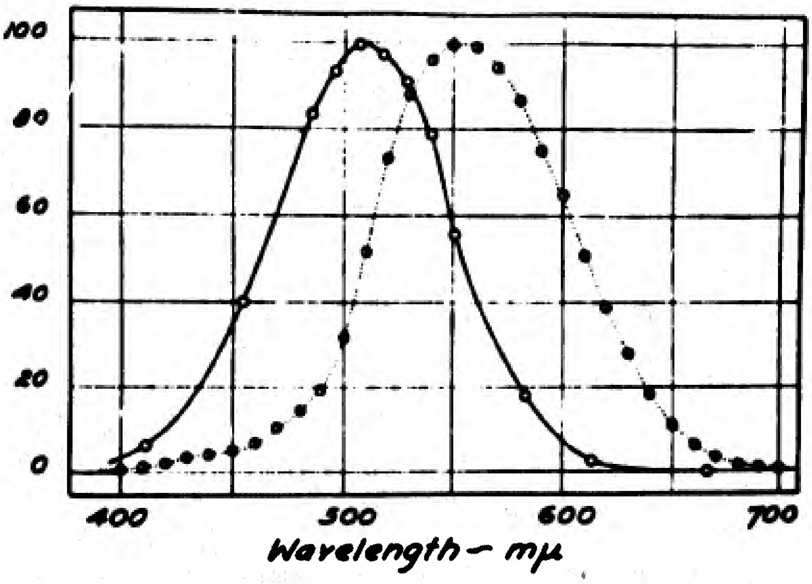
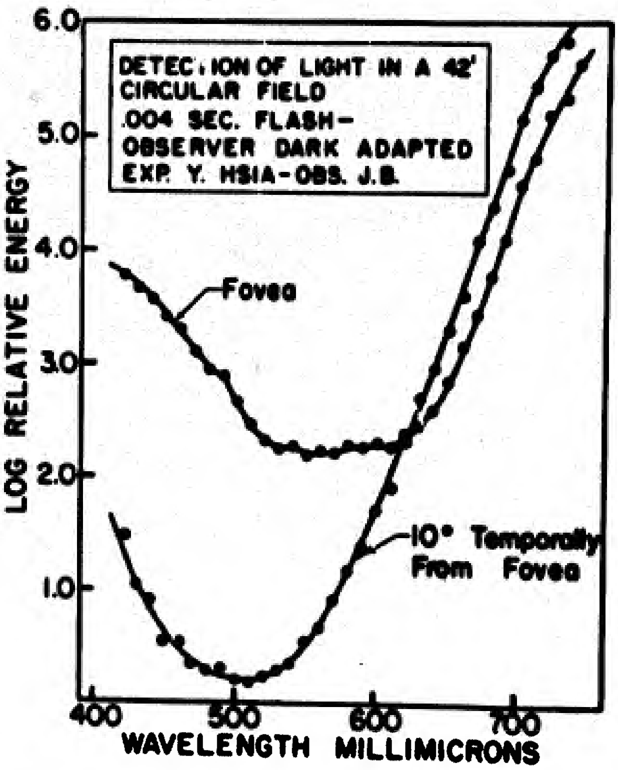


Fig. 1. Spectral sensitivity of the human eye at high (photopic) luminances (dotted curve) and at low (scotopic) luminances (solid curve). Each curve is arbitrarily set at the same maximum amplitude value.

Fig. 2. Relative energy requirements at threshold for a stimulus presented in the foveal center of the retina (photopic), and in the periphery of the dark adapted eye (scotopic) (14).



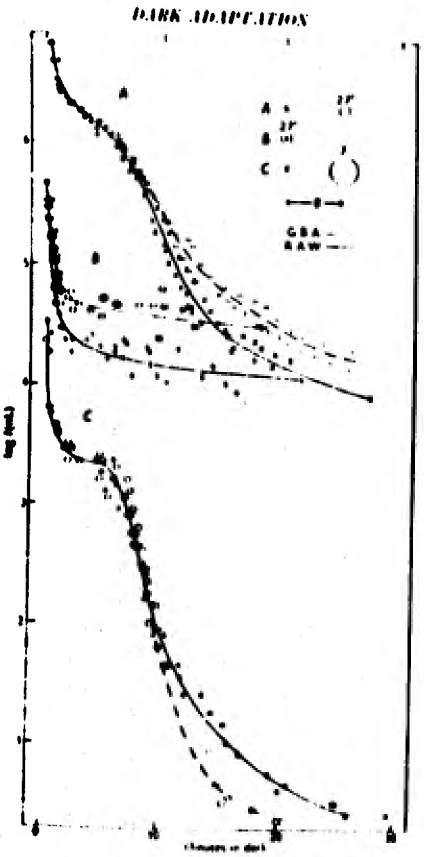


Fig. 3. Luminance threshold as a function of time in the dark for each of two observers (G.B.A. and R.A.W.) and three conditions of test. A: 2.7' field displaced 8° from fovea; B: 2.7' field centered on the fovea; C: 7° field displaced 8° from fovea (1).

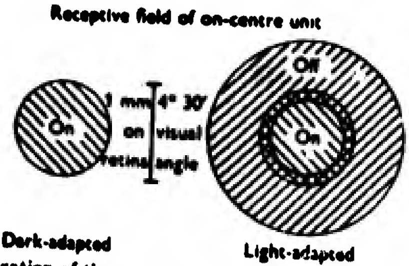


Fig. 5. Suggested organization of the receptive field of an on-centre unit in the dark- and light-adapted states. 'On' or 'off' responses to a long flash are obtained when the stimulus falls in the correspondingly labelled regions of the field. The positions of the limits to these regions have been inferred from area-threshold curves and have not been determined directly.

Fig. 4. Schematic illustration of the receptive field on the retina for a single neural unit in both the light-adapted and the dark-adapted state (4).

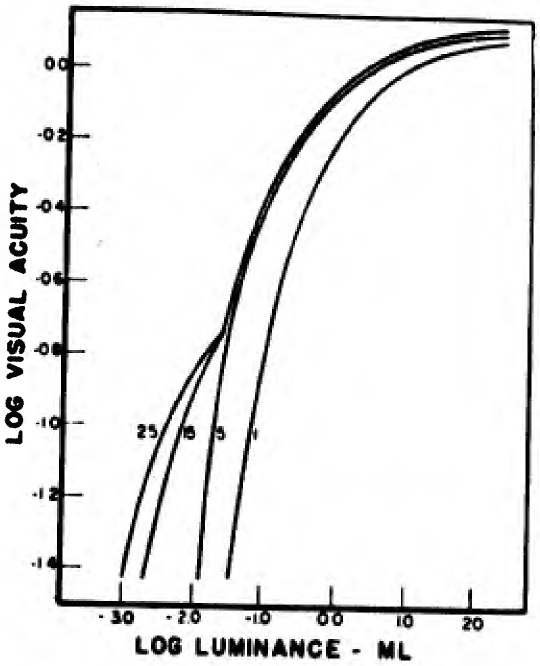
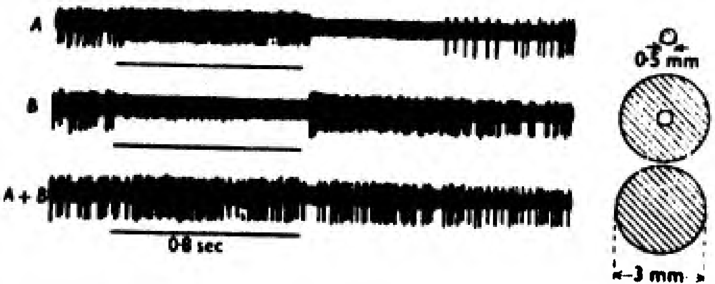


Fig. 5. Visual acuity as a function of luminance for each of four durations of dark adaptation. With sufficient dark adaptation, an early branch which represents the scotopic process is evident (10).



Text-fig. 4. Functional organization of receptive field of another cell in the inner nuclear layer; this cell also identified in that layer on the basis of all four criteria. Background retinal illuminance = 0·34 log m.c. Retinal illuminance of stimuli = 0·74 log m.c. Stimulus pattern for each response shown at right of figure, and procedure identical to that for Text-fig. 3. Stimulus repeated every 10 sec, a.c. recording, impulses 1·1 mV peak-to-peak, retouched.

Fig. 6. Records of neural response for a single unit in the visual system of the cat for each of three conditions of stimulation (19).

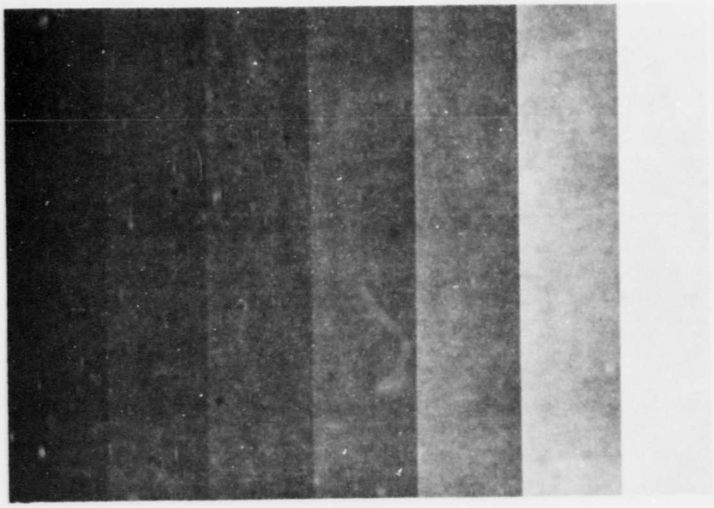
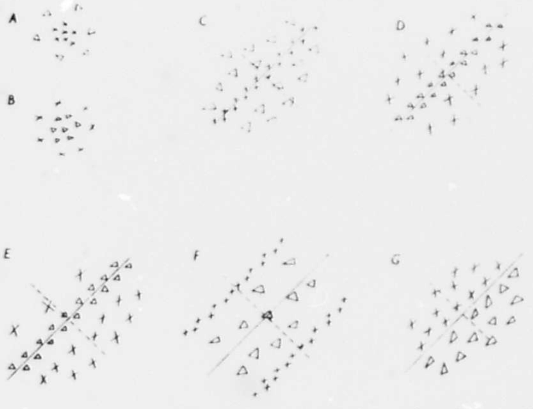
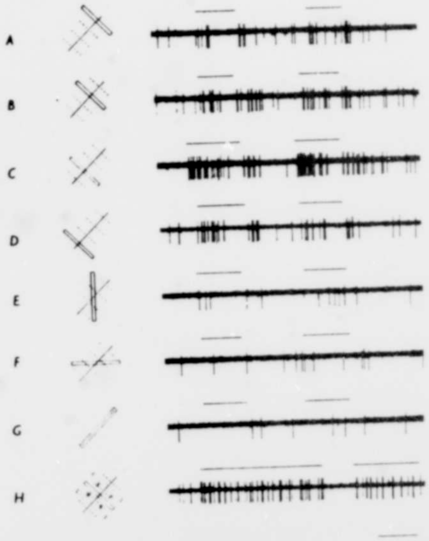


Fig. 7. Pattern of stripes of increasing lightness. The lightness of each individual stripe is uniform across its width.



Text-fig. 2. Common arrangements of lateral geniculate and cortical receptive fields. *A*. 'On'-centre geniculate receptive field. *B*. 'Off'-centre geniculate receptive field. *C*-*G*. Various arrangements of simple cortical receptive fields. ×, areas giving excitatory responses ('on' responses); △, areas giving inhibitory responses ('off' responses). Receptive field axes are shown by continuous lines through field centres; in the figure these are all oblique, but each arrangement occurs in all orientations.

Fig. 8. Patterns of excitation (x) and inhibition ( ) in the retinal receptive fields of nerve cells in the lateral geniculate body (A, B) and the visual cortex (C–G) of the cat (33).



Text-fig. 4. Responses of a cell with a complex field to stimulation of the left (contralateral) eye with a slit $\frac{1}{8} \times 2\frac{1}{2}°$. Receptive field was in the area centralis and was about 2 × 3° in size. *A–D*, $\frac{1}{8}°$ wide slit oriented parallel to receptive field axis. *E–G*, slit oriented at 45 and 90° to receptive-field axis. *H*, slit oriented as in *A–D*, is on throughout the record and is moved rapidly from side to side where indicated by upper beam. Responses from left eye slightly more marked than those from right (Group 3, see Part II). Time 1 sec.

Fig. 9. Neural activity of cortical cells in response to stimulation of the eye with rectangular light lines. Cell response is critically dependent on line orientation but not upon precise line position (33).

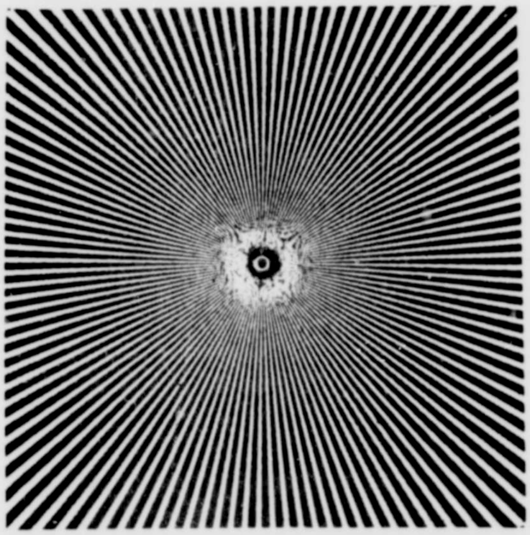


Fig. 10. Radial line adaptation pattern.

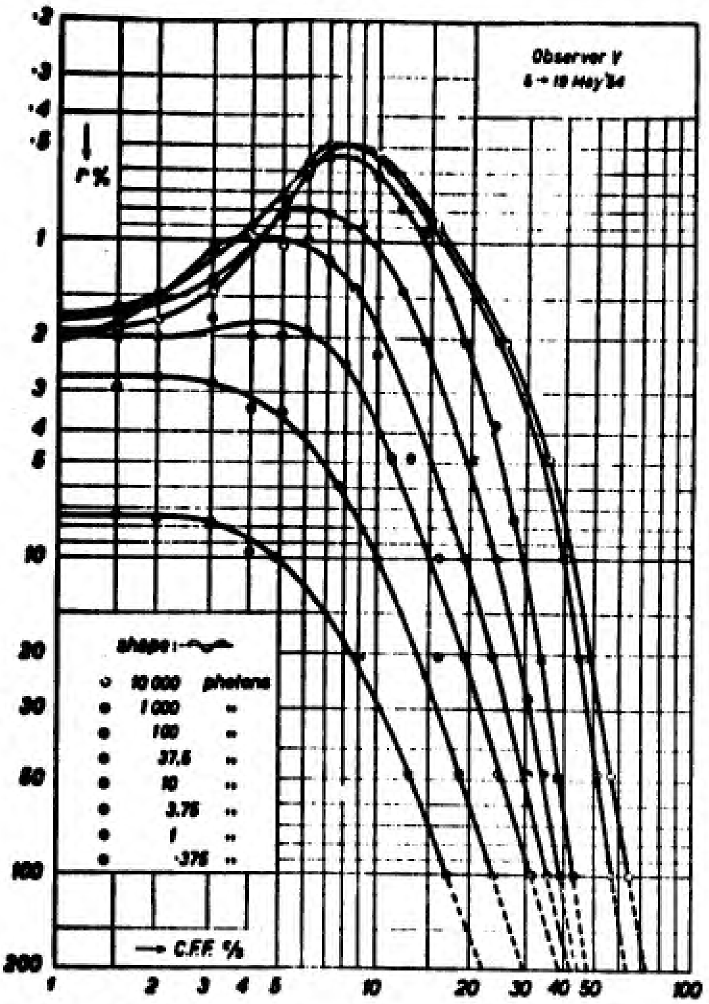


FIG. 5. A.C.'s of the brightness system for white light from 0.375 to 10 000 photons, for observer V.

Fig. 11. Modulation amplitude at which a sinusoidally varying light signal appears to fuse into a steady light. Individual curves represent different average luminances (23).

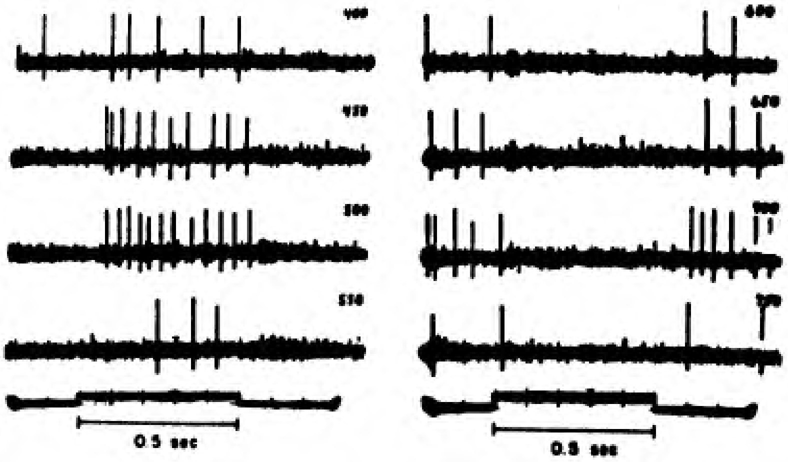


FIGURE 4. Variation of response from a single ganglion cell with change in wave length of stimulus. Wave length of stimulus in mμ at upper right hand of each record. The duration of the stimulus is indicated by the step in the signal trace at the base of each series. Spikes occurring before the onset of the stimulus are "off" responses from a preceding stimulus. Intensity of stimulus at 600 mμ = 55 μ watts/cm.² See Fig. 2 for intensities at other wave lengths.

Fig. 12. Response of a single retinal ganglion cell to stimuli of various wavelengths in nanometers (52).

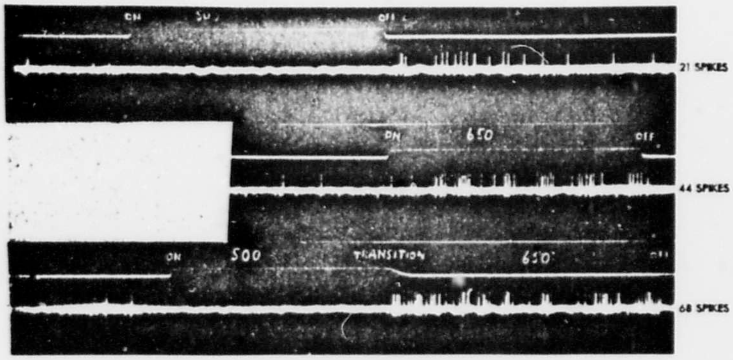


FIGURE 8. Responses of a single red-on, green-off cell. Top record: response to 500 mμ alone. Middle record: response to 651 mμ alone. Bottom record: response when 650 mμ follows 500 mμ.

Fig. 13. Responses of a single cell in the lateral geniculate body of the monkey to green (500 nanometers) and to red (650 nanometers) stimulus lights (25).

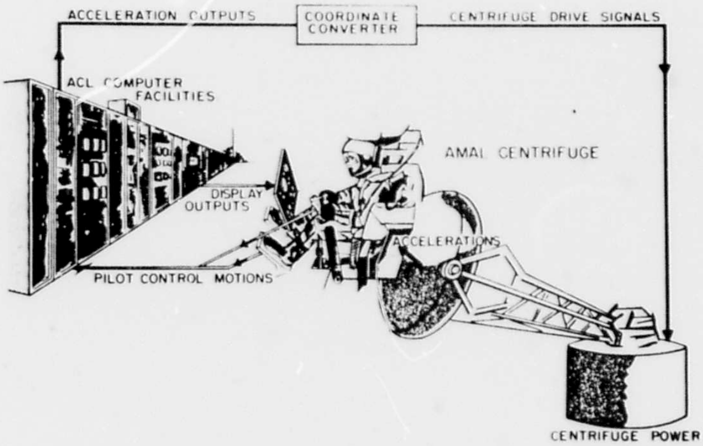


Fig. 14. Schematic illustration of system for closed-loop control simulations with the Navy centrifuge at Johnsville, Pa. (8).

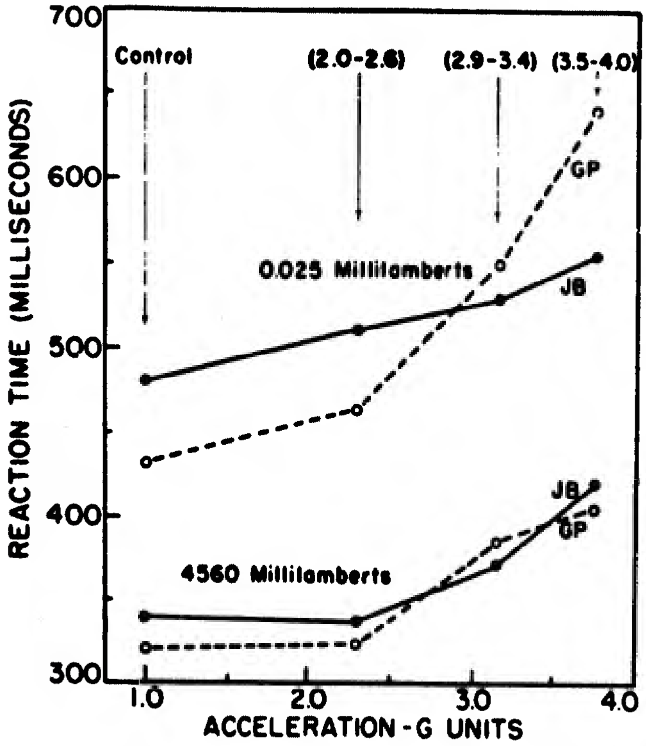
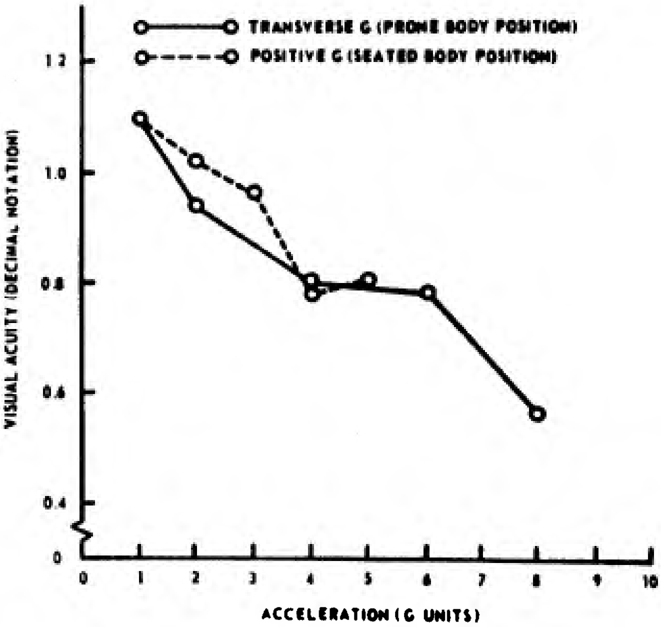


Fig. 15. Reaction time to visual signals as a function of level of positive acceleration for each of two subjects (JB and GP) and each of two luminance levels (15).

Fig. 16. Visual acuity as a function of level of acceleration in two body positions (53).



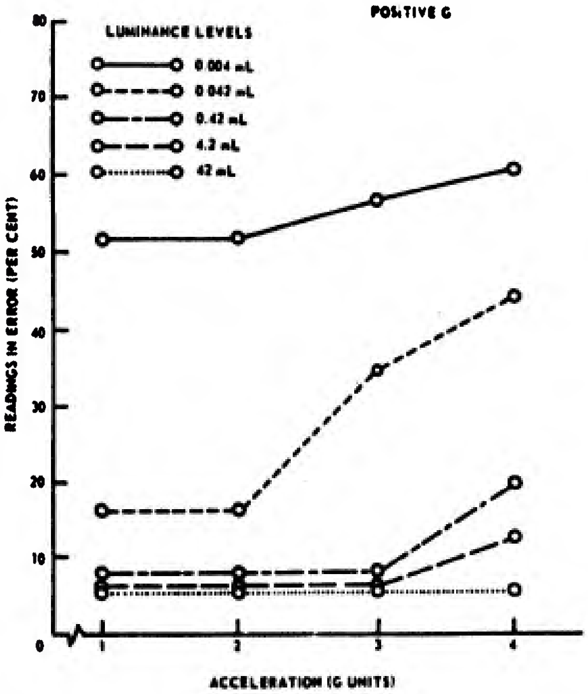


Fig. 17. Percent instrument readings in error as a function of acceleration for each of five luminance levels (53).

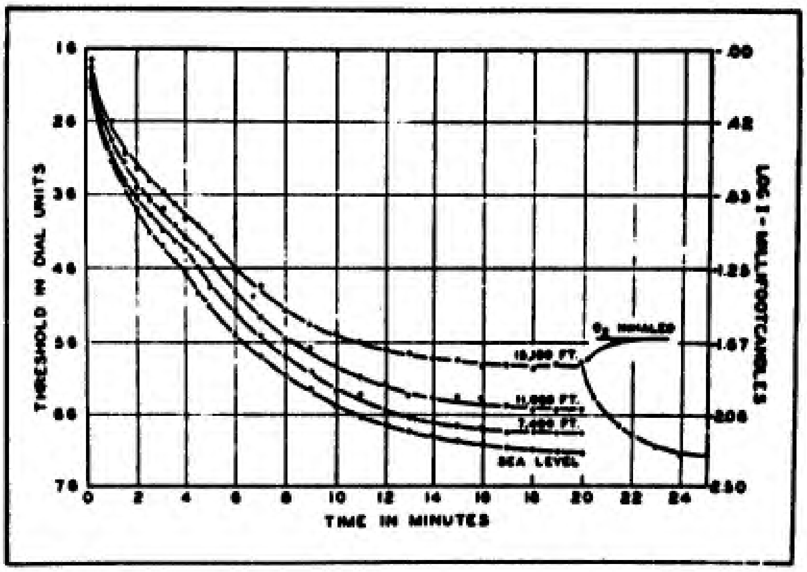


Fig. 1

Fig. 18. Dark adaptation curves at each of four pressure altitudes. Inhalation of 100% O_2 at the highest altitude is followed by a rapid drop in threshold to the level found at sea level (42).

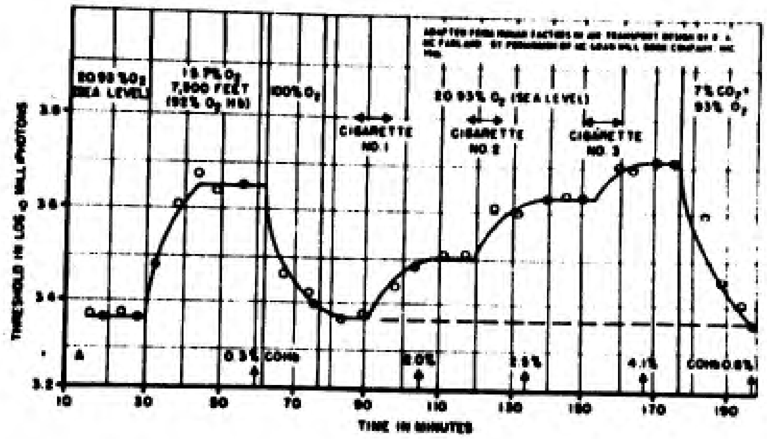


Figure 8.36 The Effect of Smoking on Visual Light Sensitivity as Compared With the Effect of Altitud
The effect of inhaling the smoke of three cigarettes is equal to an altitude of about 8000 feet. (after McFarland 8-29)

Fig. 19. Fluctuations in light threshold induced by changes in the respiratory environment and by cigarette smoking (41).

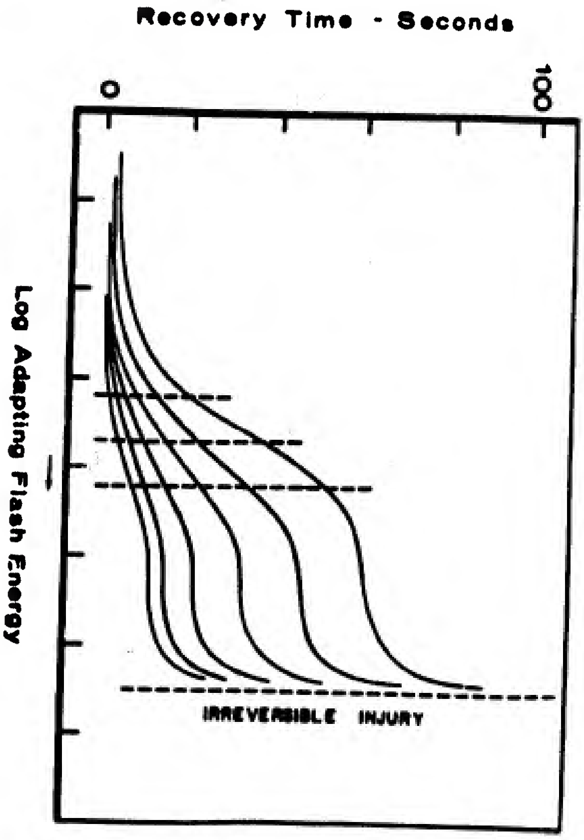


Fig. 20. Time required to recover from a bright adapting flash for each of six levels of illumination of the test criterion as a function of adapting flash energy (12).

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13. ABSTRACT

THE VISUAL REALM IN SPACE FLIGHT
by John Lott Brown

Man's presence on extended space missions is dictated by his unique effectiveness for coping with unusual situations. For his size, mass, and energy requirements, it is probable that he can handle a broader range of eventualities more effectively than any automatic equipment which might be designed. Critical elements in his performance are his sensory imput channels. The most important of these is probably vision. Visual problems which may be encountered in space flight are reviewed. The unique characteristics of the visual realm on space missions are discussed, from the instrument arrays and other aspects of space vehicle interiors, to the extravehicular situations, from rendezvous and docking with other vehicles through landing on extraterrestrial bodies and exploration of their surfaces. The significant characteristics of the human visual system, which will be essentially the same is space as on the earth's surface, are reviewed in relation to the problems which may be encountered.

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