U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

REPORT NUMBER 588

A PRELIMINARY INVESTIGATION OF THE EFFECTS OF NEAR INFRARED RADIATION ON VISUAL PERFORMANCE

by

Kevin Laxar

Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4305.08-3001D.04
NavAirSysCom Airtask No. A34531/562/69F32523401

Approved and Released by:

J. E. Stark, CAPT MC USN
COMMANDING OFFICER
U. S. Naval Submarine Medical Center

7 July 1969

A PRELIMINARY INVESTIGATION OF THE EFFECTS OF NEAR INFRARED RADIATION ON VISUAL PERFORMANCE

by

Kevin Laxar

SUBMARINE MEDICAL RESEARCH LABORATORY
NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 588

Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4305.08-3001D.04
NavAirSysCom Airtask No. A34531/562/69F32523401

Transmitted by:

George Moeller
Head, Human Factors
Engineering Branch
Sub Med Res Lab

Reviewed and Approved by:

Charles F. Gell

Charles F. Gell, M.D., Sc. (Med)
Scientific Director
Sub Med Res Lab

Reviewed and Approved by:

Joseph D Bloom.

J. D. Bloom, CDR MC USN
Director
Sub Med Res Lab

Approved and Released by:

J. E. Stark, CAPT MC USN
COMMANDING OFFICER
Naval Submarine Medical Center

SUMMARY PAGE

THE PROBLEM

To investigate the effects of near infrared radiation on visual performance.

FINDINGS

Near infrared radiation similar to solar spectral distribution and intensity caused no apparent eye damage or decrement in performance on a visual discrimination task in Rhesus monkeys. Evidence was found of an avoidance response to the radiation.

APPLICATION

The study provides evidence that the tinted plastic visors currently in use by U. S. Navy pilots afford sufficient eye protection from the sun's near infrared radiation, even at high altitudes. Findings also indicate that personnel would not be subject to eye injury from such artificial sources as infrared searchlights if they remained at a distance to prevent experiencing greater than the 70 mw/cm^2 used in this study.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit M4305.08-3001—Medical Human Factors in Submarines, and NavAirSysCom Airtask No. A34531/562/69F32523401—Optical Protective Devices and Eye Protection Techniques. The present report is No. 4 on Work Unit M4305.08-3001, and also a report on Airtask No. A34531/562/69F32523401. It was approved for publication on 7 July 1969 and designated as Submarine Medical Research Laboratory Report No. 588.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL CENTER

ABSTRACT

Simulated solar, near infrared radiation caused no eye damage or decrement in visual discrimination performance in Rhesus monkeys. The subjects tended to avoid the radiation, however. The study provides evidence that 70 mw/cm^2 is a safe level of irradiance for repeated exposure to the near infrared in operational settings. Distance from the source is the limiting factor in exposure to infrared searchlights and signaling devices. No change in visor specification is required to protect Navy personnel from the sun's near infrared radiation, even at high altitudes.

A PRELIMINARY INVESTIGATION OF THE EFFECTS OF NEAR INFRARED RADIATION ON VISUAL PERFORMANCE[1]

INTRODUCTION

Modern naval operations at sea present a potential source of eye damage from high-powered infrared signaling and communication devices. Under certain conditions, exposure to such radiation from searchlights or beacons could subject the eyes to an irradiance similar to that of the sun. In addition, current research trends imply use of laser devices for communication and ranging techniques in underwater operations, with consequent hazards to swimmer and diver vision.

The increasing number of high altitude and orbital flights has prompted the study of the effects on man of various wavelengths of radiation without their attenuation by earth's atmosphere. Of particular importance are the effects of such radiation as solar radiation, alpha, beta, cosmic, and x-rays upon man's eyes and his visual performance (McDowell & Brown, 1960). It has been shown that ionizing radiations such as beta and x-rays produce cataracts (Davson, 1962a), and that erythemal ultraviolet (240 to 320 mμ) causes damage to the cornea and to other external parts of the eye (Verhoeff & Bell, 1916; Matthews, 1949). Verhoeff and Bell (1916) also investigated the production of "eclipse burns," permanent blind spots in the visual field caused by looking into the sun or any other high intensity light source for a sufficient length of time.

In specifying the transmittance properties of a visor for use at high altitudes the amount of near infrared[2] (IR) transmittance tolerable has been an unresolved problem. In the visible transmittance range, 380 to 760 mμ (Illuminating Engineering Society, 1962), Lythgoe (1932) has shown that the reduction of extreme intensities results in greater eye comfort without any appreciable loss in visual acuity. The injury threshold for erythemal band ultraviolet has been well documented, but the effect of infrared radiation and its maximum permissible amount has never been assessed (Farnsworth, 1948). In addition, most pilots' visors are made of plastic, which can effectively be dyed to absorb ultraviolet and visible radiation but which always transmit large amounts of near IR (American Standards Association, 1955).

This report describes an investigation designed to determine whether or not there are structural changes in the eye and functional changes in visual performance resulting from exposure to IR at a nominal irradiance of 70 mw/cm^2, that of solar IR output (Johnson, 1954; Rocco, 1967). Findings of the study are relevant to the several practical problems outlined above.

The early literature regarding the effects of IR was primarily conjectural. In note of this, Luckiesh (1919) presented the facts known to that time about IR and its effect on the eye. He mentioned contradictory British investigations on glass workers' cataract, supposedly due to IR, and indicated that eye fatigue, irritation, and cataracts were attributed to IR effects without substantiation.

1. This report was submitted to the University of Connecticut in partial fulfillment of the requirements for the Master of Arts degree. This study was conducted according to the principles enunciated in "Guide for Laboratory Animals Facilities and Care."

2. Heat rays, generally considered to be those wavelengths between 0.760 and 10 microns (Illuminating Engineering Society, 1962) and hereafter referred to as IR.

Luckiesh also suggested that the confusion regarding IR effects was probably based on the common property of ultraviolet, visible, and IR radiation, i.e. their conversion of radiant energy to heat upon absorbtion, the mechanism which Verhoeff & Bell (1916) found produces eclipse blindness. This process was later formalized by Vos (1959). The dependence of localization of damage within the eye upon the visual size of the illuminating source was explained by Luckiesh on the basis of the eye's optics. A high intensity source of illumination of very small subtense would produce a high energy density near the retina, while an extended source of relatively low brightness would produce a high energy density in the lens.

Despite Luckiesh's efforts, no systematic study of IR effects ensued. Subsequent publications generally accept the early conclusions that IR caused cataracts in glass workers (Kutscher, 1946; Matthews, 1949; LeGrand, 1952), offering only ocular absorbtion data as an explanation of previous conclusions. Several modern text books predict the occurrence of cataracts from radiation sources of unspecified intensities, without cited evidence (Duke-Elder, 1954; Davson, 1962a; Hogan & Zimmerman, 1962; Prince, 1964). When evidence is cited, reference is always to very high energy levels. In a survey of glass workers, Dunn (1950) found no evidence of cataract or any other eye abnormality in workers with many years of intense IR exposure, casting serious doubt on the previous English investigations and on the role of IR in eye damage. A review of the injurious effects of sunlight by the Naval Medical Research Institute (1944) described the agreement with Verhoeff & Bell by many subsequent investigators, and concluded that the sun's radiation is of doubtful importance in the production of cataracts.

A study of the functional effects of IR was reported by Luckiesh & Moss (1937) in which the visual function of readers was compared using light from incandescent lamps with light from the same lamps filtered through three inches of water which absorbs some of the thermal radiation. Reading rate, blink rate, pupil diameter and other measures were compared and no differences found, the conclusion being that the IR caused no deleterious effects. The light intersity used in this report, however, was far below the level required for generalization to solar intensities.

Most attempts to determine eye damage thresholds for visible and infrared radiation have been concerned only with the retina, and have employed high energy bursts of short duration, often using monochromatic light (lasers) rather than a broad band of wavelengths. The obtained power density thresholds for permanent eye damage (Bredemeyer, Wiegmann, Bredemeyer, & Blackwell, 1963; Fine, Berkow, & Fine, 1968; DeMott & Davis, 1959) are in the range of about 2.5 to several hundred times the power density of extraterrestrial sunlight, 140 mw/cm^2 (Johnson, 1954). Such wide variations in procedural parameters make prediction of the effects of sustained or repeated high altitude solar exposures impossible (Bredemeyer et al., 1963).

Specifications of eye protective equipment require that the amount of IR transmitted should always be less than that of the visible. The American Standards Association's specifications for filters for industrial use (1960) are in great part basel on a review by Stair (1948), who states that lenses should protect the eyes from the injurious ultraviolet and infrared rays and excessive radiant energy of any wavelength. He further stated that because ultraviolet and IR are of no aid to vision they should be eliminated if at all economically feasible, to reduce the risk of injury. In the ASA's specification of plastics for use in eye-protection (1955), the amount of infrared from sunlight, at least near sea level, is considered of minor importance. Caution is advised, however, against acquiring retinal burns by using non-IR-absorbing plastic sunglasses to protect the closed eyes while lying face up at the beach.

Farnsworth, in his sunglass requirements (1948), considers IR as a probable cause of cataracts or at least some visual damage or disturbance. He provides anecdotal evidence that the removal of only the near IR from a brightly sunlit scene resulted in more comfortable viewing with less squinting. Miller

(1962) points out many threats to the eye during space travel, among them the extended high intensity light source caused by reflection from the earth's atmosphere, the glare of the solar disk, and the increased chances of damage from higher intensities of cosmic, alpha, proton, UV, and IR radiation. Rocco's (1967) approach for protecting the astronaut from solar radiation was to set a maximum facial temperature of 100° F to determine the relative amounts of radiation transmittance permissible.

Still lacking in the literature is evidence of long term effects of IR in doses similar to that which man encounters in sustained or repeated high altitude flight. A study was therefore undertaken to determine if any eye damage or decrement in visual performance would occur during or after many hours of exposure to the quantity and quality of IR encountered outside the earth's atmosphere or from similar artificial radiation near or under the sea. The following were hypothesized: that no immediate ocular injury would occur, but that long term exposure might well cause damage; and that the amount of discomfort and visual fatigue caused by the heating effects would be evident in a measure of response rate or error rate on a visual discrimination task, or in a measure of avoidance responses while performing that task.

METHOD

Subjects

Due to the risk of eye injury, monkeys rather than humans were used as subjects (Ss). Rhesus (**Macaca mulatta**) were chosen for their similarity to man in their ocular structure and function (DeValois & Jacobs, 1968; Graham, McVean, & Farrer, 1968). Ss were two females, approximately four years old. S1 weighed 4.1 kg. and S2 weighed 5.4 kg. Both were maintained at two-thirds their normal diet, reducing their respective body weights to 72% and 86% of normal. S1 was experimentally naive; S2 had been used in an auditory discrimination experiment two years earlier. Ss were housed in individual cages and for each session were placed by **E** in a Foringer restraint chair and transported to the experimental booth in a carrying box.

Apparatus

To stimulate the IR portion of the solar spectrum and eliminate the visible and ultraviolet, the output of a 240 watt spot lamp, General Electric 240PAR56VNSP, was filtered through a 6½ inch square Corning Glass infrared filter No. 2540. Figure 1 compares the resultant beam with solar IR radiation outside the earth's atmosphere. The spectral distribution of the source is also representative of U. S. Navy IR searchlights.

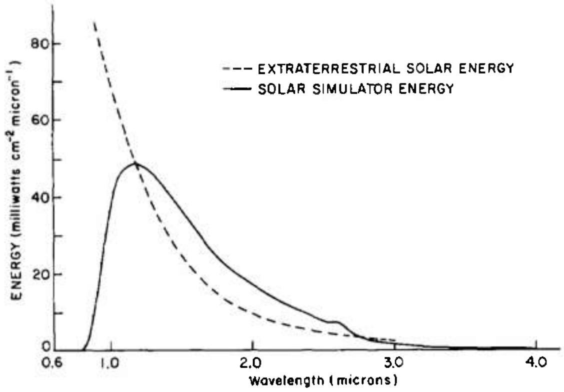

Figure 1. Intensity vs. wavelength of extraterrestrial solar radition and simulated source in near IR. **NOTE:** ***The solar radiation curve is from Johnson (1954). The curve of the simulated source was calculated from color temperature curves (General Electric Company, 1953), and filter transmittance data from spectrophotometric measurements by the author and by Corning Glass (1965).***

Because half the extraterrestrial solar energy is in the IR portion of the spectrum (Rocco, 1967), the power density of the experimental IR source was 70 mw/cm^2 (Johnson, 1954). Irradiance was measured with a Yellow Springs Instrument Model 65 radiometer, and the desired level was achieved by adjusting the distance between the lamp and the radiometer sensor mounted in S's normal eye position. With the equipment arranged as shown in Figure 2, the infrared source projected a beam of uniform irradiance over an area 5½ inches square, centered about S's head. The source subtended a visual angle of 10.1 degrees diameter. A voltage stabilizer and a variable transformer were used to power the spot lamp and to make fine adjustment of intensity.

For the experimental sessions, the sensor was mounted just behind and slightly above S's head (see Figure 3).

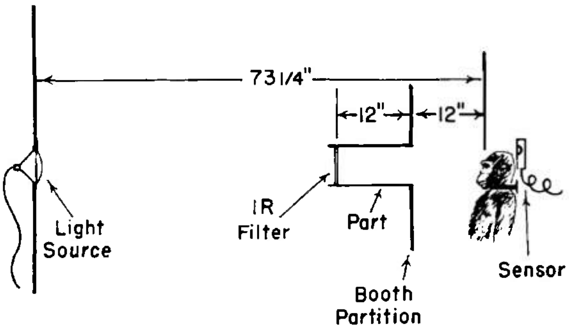

Figure 2. Physical layout of IR solar simulator.

The power density of the source in all IR sessions was continuously monitored with the radiometer and was recorded on a Sanborn Model 60 strip chart recorder.

Due to the high intensity of the IR, the radiation was visible as a deep red glow (Davson, 1962b). For control sessions a "dummy IR" filter was constructed of thick red plastic. When illuminated from the rear by the spot lamp burning at 8% of its normal voltage, this source was visually similar to the true IR. The power density from the dummy IR was less than 0.01 mw/cm^2.

The operanda were standard Foringer Model 1224M1 transparent press plate keys with Model 1228-I rear projection cells mounted behind them. The figures displayed had a minimum height of 0.72 inches, for a visual angle of 3.4 degrees, and a minimum stroke width of 0.088 inches or 25 minutes of arc. Because the Rhesus, like man, can quite easily resolve visual angles of less than one minute of arc (Graham et al., 1968), 0.6 neutral density Wrattan filters were placed over the display cells to reduce luminance. This reduction made the task more difficult, for a closer approximation to practical in-flight situations. With the neutral density filters in place, the figures averaged 7.0 ft.-Lamberts brightness on a background of 0.15 ft.-Lamberts[3] The contrast value of 45.7, however, was still far above the threshold contrast of 0.2 for the given conditions (Blackwell, 1946).

Scientific Prototype digital programming equipment was used to control a cumulative response recorder, digital counters, and an IBM Model 024 card punch. The card punch was modified to present stimuli and reinforcement in sequences pre-punched into a card deck. The programming and recording equipment was contained in an isolated control room.

The experimental booth was a partitioned section approximately three by four feet in the corner of a sound insulated, air conditioned room. The air temperature in the booth was held at 71 ± 2°F for all experimental sessions. Indirect ceiling illumination provided three foot-candles at S's eye level. The front wall of the booth, facing S, was painted flat gray, reflecting a brightness of 0.2 ft.-Lamberts. The wall contained a port in the middle, through which the IR source, 4¼ inches in diameter, was introduced. One display cell with response key was located on each side of the IR port, 3⅝ inches center-to-center from the port on the horizontal midline through the port. The food cup was mounted seven inches from the bottom of the IR port (see Figure 3).

To remotely observe S's activity, a closed circuit television camera was mounted on the booth wall and aimed down on S. A monitor in the control room displayed a top view of S, and parts of 18 sessions were recorded on video tape.

Procedure

Ss were trained on a two-choice form discrimination task. Figures illuminated on the display cells were a plus sign, square, triangle, and circle. The former two presented the smallest and largest illuminated areas. They were chosen as the positive stimuli to control for discrimination based solely on

3. Brightness measurements were taken with a General Electric Co. Luckiesh-Taylor Brightness Meter.

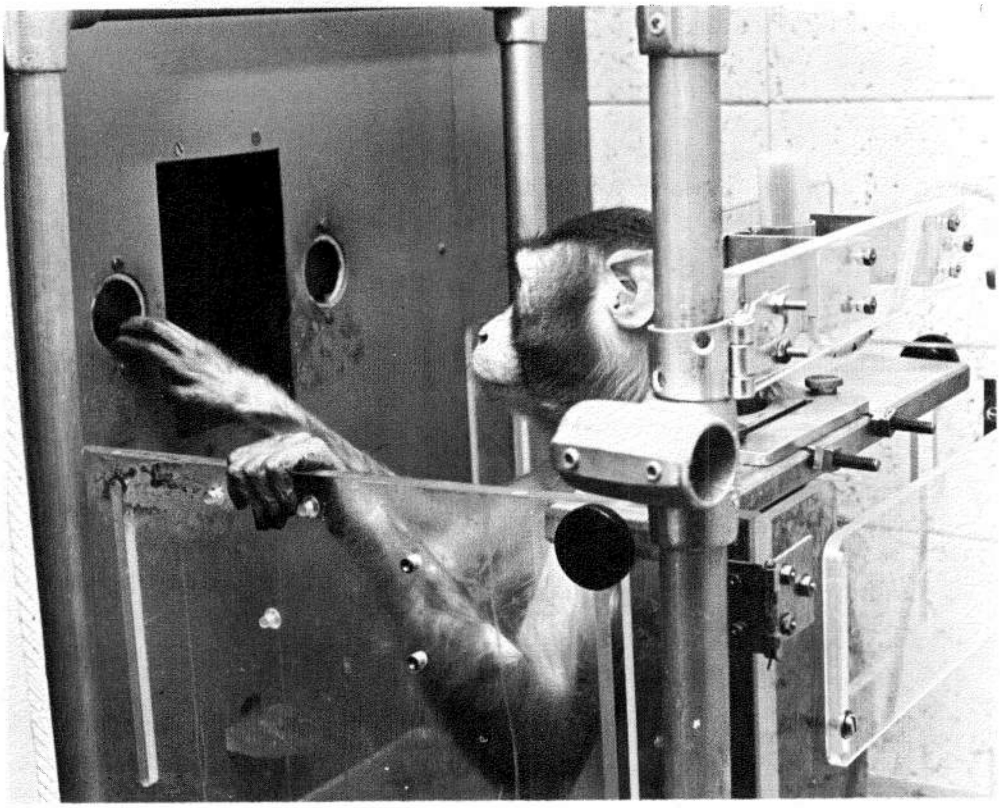

Figure 3. Subject performing visual discrimination task.

total luminous flux (Schilder, Pasik, & Pasik, 1967). Every trial consisted of one positive and one negative stimulus. A trial began with the onset of the stimulus figures, and a response to either began an intertrial interval (ITI), during which the stimulus projectors were blank and the response keys inoperative. During the experimental sessions, the eight stimulus-position pairs were varied according to the Fellows series (1967), so that (1) the positive stimulus occurred at an average of 50% of the trials on each side, and (2) each of the eight pairs was presented an equal number of times in any session. No limit was imposed on response latency, but after the initial training, balking was very rare and of short duration. Reinforcement was a 190 mg. CIBA banana flavored nutrient pellet. No negative reinforcement was used so that Ss' cooperation would be maintained throughout the course of the experiment (Sidley, Sperling, Bedarf, & Hiss, 1965). A neck yoke was substituted for the plastic neck plate on the restraint chair to enable S to view the stimuli, respond, and feed herself pellets.

For each session the counters recorded the numbers of left incorrect responses, right incorrect responses, total responses, and reinforcements. The cumulative response recorder provided conventional operant conditioning graphs.

Pre-training began by shaping the key-press response with a positive stimulus (plus) in both positions. The ITI was increased over the course of this training when the response rate stabilized at each ITI value. Discrimination training was begun at 100% reinforcement with an ITI of two seconds, gradually increased to five. The training criterion was 85% correct responses at a stable response rate of six responses per minute for 200 trials. Ss were trained to criterion first on the plus-circle discrimination, then on the square-triangle pair, and finally on a sequence of all eight stimulus-position pairs. Reinforcement was then changed to a variable ratio of 50%, following the Fellows series, and the ITI was increased to eight seconds. Training continued on this final schedule for six sessions per animal, 400 trials per session.

The experiment consisted of 35 sessions, the first six and last five being control sessions, with five series of four IR sessions in between. A control session intervened between IR series to maintain response rate, in view of the hypothesized behavioral interference. Ss were run for one session per day, usually five days per week. Each 400-trial session lasted approximately one hour and never exceeded 68 minutes.

For IR sessions, the solar simulated beam was turned on at the start of the session and remained on for at least 60 minutes. For control sessions, the dummy IR was substituted for the high intensity beam. Pupillary responses to the IR and dummy IR beams were determined by direct observation of Ss' eyes in a session for that purpose. No pupillary responses were elicited by the onset or offset of the respective beams. Each S received a cumulative total of 20 hours of the IR over a period of five weeks. The radiometer records showed that the irradiance for all IR sessions was stable and at the correct level.

The average time S spent avoiding the IR (or dummy IR) beam was measured in alternate five minute periods of each session. On the television monitor screen was drawn the scaled horizontal extent of the IR beam. Whenever S's head was turned so that one or both eyes were outside the inscribed area, avoidance time was cumulated. To establish reliability of timing and assess any experimenter bias, the 18 video taped sessions were again timed by **E** and another observer, independently and without knowledge of experimental conditions. Correlation coefficients among **E**'s original timings and the taped timings exceeded 0.70 and were highly significant.

Ocular examinations and retinal photographs were performed by an optometrist during the initial control sessions and after the final experimental session. For the photographs, a Zeiss Fundus Camera was used, and Ss were lightly anesthetized with intraperitoneal injections of Nembutal.

RESULTS

Eye examinations and a direct comparison by an ophthalmologist of retinal photographs taken before and after exposure to the IR showed no evidence of any change or damage to the ocular structure of either animal.

Frequency of errors for both Ss is shown in Table I. Most of the errors occurred within the first few minutes of each session, while the animal was settling down to the task. In view of this fact and that the proportion of errors under both control and IR conditions was so small, further analysis of error frequencies was considered unnecessary.

TABLE I
Error Frequency by Experimental Session

Subject	Condition: Control (6000 Responses)	IR (8000 Responses)	Total
S1	9	10	19
S2	15	18	33
Total	24	28	52

Figure 4 shows length of avoidance time per five minute block, and operant response rate, for each experimental session. Avoidance time was less than 20% of the total session time. For S1 the response rate remains fairly constant throughout the experiment. The mean avoidance time per session shows a general increase throughout the experiment, however, except for the last five control sessions. In addition, the avoidance time of IR sessions appears to be greater than that for control sessions.

The response rate for S2 was more variable than that for S1 and there was a noticeable decrease in response rate after session 20. The difference in avoidance times between control and IR conditions is also apparent in

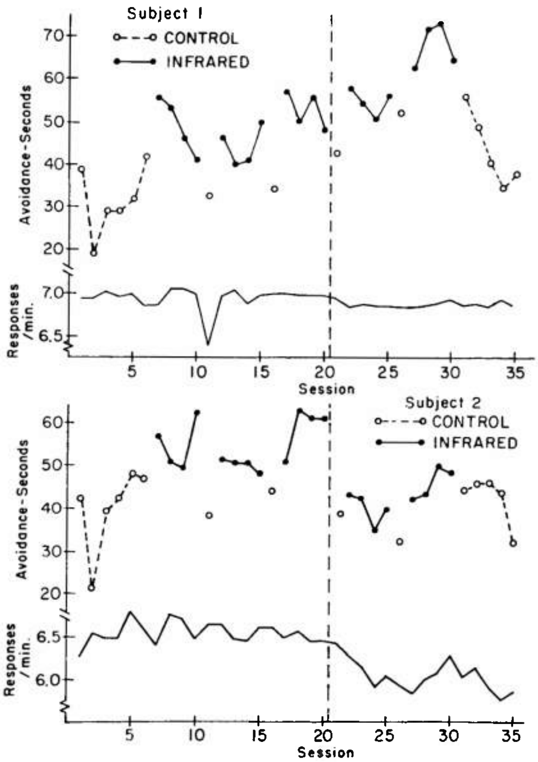

Figure 4. Mean avoidance time per five-minute block and operant response rate by session.
NOTE: ***The vertical dash line after session 20 indicates a break point in data analysis, not a change in experimental condition.***

TABLE II
Analysis of Variance of Avoidance Times: All IR Series

Source	df	MS	F
Subjects (A)	1	17.49	
Treatment (B)	1	868.56	44.76
Series (C)	4	41.65	0.26
A x B	1	19.40	
A x C	4	160.85	
B x C	4	18.22	3.71
A x B x C	4	4.91	

TABLE III
Analysis of Variance of Avoidance Times: First Three IR Series

Source	df	MS	F
Subjects (A)	1	140.56	
Treatments (B)	1	670.06	228.69*
Series (C)	2	39.19	26.13*
A x B	1	2.93	
A x C	2	1.50	
B x C	2	7.05	6.41
A x B x C	2	1.10	

* $p<0.05$.

TABLE IV
Analysis of Variance of Avoidance Times: Last Two IR Series

Source	df	MS	F
Subjects (A)	1	446.71	
Treatments (B)	1	221.98	9.35
Series (C)	1	54.19	0.77
A x B	1	23.73	
A x C	1	70.68	
B x C	1	35.35	3.47
A x B x C	1	10.18	

TABLE V
Analysis of Variance of Response Rates

Source	df	MS	F
Subjects (A)	1	5.42	
Treatments (B)	1	1.24	1.70
Sessions (C)	14	0.02	1.00
A x B	1	0.73	
A x C	14	0.019	
B x C	14	0.019	1.19
A x B x C	14	0.016	

S2's data, but the overall increasing trend exhibited by S1 holds only to session 20 for S2. In contrast, sessions 21 to 35 show reduced avoidance response times.

Table II shows the analysis of variance (Lindquist, 1953) of the mean avoidance times for the five experimental series. For this analysis, each series, consisting of four IR sessions and the preceding control session, provided two means, one for each type of session per animal. No statistically significant effects of radiation, Series, or their interaction were found. The error term for each F ratio was the appropriate mean square interaction with subjects.

Based on avoidance time and response rate data the assumption was made that a change in S2's performance habits occurred after session 20. Additional analyses were performed to determine whether this assumption was correct, and, if so, its cause and extent.

TABLE VI
Analysis of Variance for Linear Regression of Response Rates:
Subject 1, Sessions 1-20

Source	df	MS	F
Total	19	0.0203	
Regression	1	0.0011	0.0516
Error	18	0.0213	

TABLE VII
Analysis of Variance for Linear Regression of Response Rates:
Subject 1, Sessions 21-35

Source	df	MS	F
Total	14	0.0013	
Regression	1	0.000026	0.0186
Error	13	0.001401	

An artificial break in the data was made between sessions 20 and 21. Separate analyses of variance were performed on the avoidance time data of the first three IR series (Table III) and on the last two IR series (Table IV), comparing each IR series mean with its respective previous control session mean as in the first analysis. Treatment effect and Series effect were both significant for the first three IR series, but not for the last two. These results indicate that up to a point, the effect of the IR on avoidance responses was significant, and that some change occurred during the experiment to make this effect over the entire experiment non-significant. Treatment effect for the entire experiment yielded a $\mathbf{p} < 0.10$, but not $\mathbf{p} < 0.05$.

TABLE VIII
Analysis of Variance for Linear Regression of Response Rates:
Subject 2, Sessions 1-20

Source	df	MS	F
Total	19	0.01726	
Regression	1	0.00053	0.0291
Error	18	0.01819	

For an analysis of variance of response rates, sessions six through 20 and sessions 21 through 35 were considered as separate treatments. No significant differences in the levels of response rate were found (see Table V).

TABLE IX
Analysis of Variance for Linear Regression of Response Rates:
Subject 2, Sessions 21-35

Source	df	MS	F
Total	14	0.03435	
Regression	1	0.1380	5.23*
Error	13	0.02638	

* $p < 0.05$.

Earlier inspection of S2's response rate, however, showed a gradual decline beginning with session 21. For evidence of this decline, analysis of variance for linear regression (Hays, 1963) were performed on the response rates of each subject for sessions 1 through 20 and 21 through 35. The only regression line slope that showed a significant difference from zero was that of sessions 21 through 35 of S2. These analyses are presented in Tables VI through IX, and are offered only as an indication of a change in S2's behavior.

DISCUSSION

No significant decrement in performance was obtained on the relatively gross visual discrimination task, although the evidence would seem to indicate the temporary existence of an avoidance response to the IR. Ss were often observed under IR conditions rubbing their eyes with their paws or placing their arms before their faces as if to shield their eyes from the thermal energy.

Even though the discrimination was quite easy, it was not insensitive to disruptive events. It is clear that some unknown event had an appreciable effect on S2's performance. The decrease in length of avoidance response with a concurrent drop in response rate would seem to indicate a general suppression of activity. No explanation can be given for this effect. The S's normal highly active manner did not appear to change outside the experimental situation, nor did her apparent general health, weight or diet. This monkey, however, was relatively bright, as judged by her performance on earlier auditory tasks and by the speed at which she learned the visual task employed here. The possibility exists that she learned to close her eyes, which would certainly tend to lower the response rate as well as decrease the avoidance response. Eyelid closure could not be observed on the closed circuit television because of the superior angle of view. Other variables, however, such as reinforcement ratio or motivation level could affect performance on this task, especially over the time span covered.

The possible effect of the IR radiation on avoidance behavior suggests further study. An avoidance situation, using the IR as an aversive stimulus, might provide a clear demonstration that this level of IR is undesirable.

Additional controls to be taken in a more comprehensive study might involve the following: a large N to minimize the effects of individual differences; controlled diets to give equal percent of weight reduction for all Ss; and a fixed session duration for all Ss under both conditions. An exact color match between the IR and dummy IR beams would be desirable, though perhaps of minor importance. To increase the performance sensitivity to interference effects, response latency and smaller discriminanda, approaching the limits of visual acuity, could be employed. A shorter ITI would increase S's work load, possibly resulting in greater changes in response rate and error rate. A more precise measure of eye position and movements would be afforded by directly recording them on film. To better control for IR exposure, greater limitation of S's head movement would be required.

In the present study the simulation of IR exposure was reasonable for short aircraft flights. Since exposure to IR in sea operations would typically be of shorter duration than in aircraft situations, the remainder of the discussion will be devoted to the latter. The exposure was at least as great as that experienced in flight in the respect that for 80% of each session the IR beam was directly on the S's eyes. The eye movements of a pilot, changing his gaze in and out of the cockpit (Miller, 1962), would normally exceed those of the animals in this study. In addition, the IR level of irradiance slightly exceeded the maximum encountered in high altitude flight, except for the very unusual occurrence of direct fixation of the solar disk, or the pilot's orientation so as to receive additional energy from reflections by his vehicle, the earth, or its atmosphere (Rocco, 1967). A further bias towards pilot safety is the slightly heavier pigmentation in the Rhesus eye, resulting in a lower retinal thermal lesion threshold than that of a human eye (Geeraets, 1968).

The evidence from this investigation that no immediate eye damage occurs from the power density of IR used is in agreement with damage threshold data from short duration energy bursts. The results indicate that the eye, in a normal room temperature environment, is capable of dissipating solar thermal radiation. Damage might occur, however, if the length of each session, or the number of sessions were increased, due to the possibility of everloading the heat dissipation capabilities with increased exposure duration or greater cumulative effects (Mayer & Richey, 1964).

The present study provides no substantial evidence that the IR protection furnished by present plastic visors is inadequate. On the basis of incident energy, a typical plastic visor with maximum transmittance value of 0% in the ultraviolet, 15% in the visible, and 87% average in the IR (ASA, 1955) would protect its wearer from experiencing more than 70 mw/cm^2, the irradiance used in this simulation. Visor characteristics could be changed, however, by such means as a thin metal coating to exclude a large proportion of the IR. The erythemal band of the ultraviolet would still be screened out and the transmittance in the visible range would be sufficient to afford good visual acuity. Evidence from the avoidance behavior suggests further study along these lines, with a view towards improving the pilot's comfort directly and his efficiency indirectly.

ACKNOWLEDGMENT

The author wishes to express his gratitude to the following members of the Naval Submarine Medical Center Staff for their assistance in the conduct of this study: Dr. G. O. Moeller, Head, Human Factors Engineering Branch; R. J. Kaiser, CDR MC USNR; P. J. Whelan, LT MC USNR; L. J. Zglobicki, LT

MSC USNR; and Mr. C. P. Chattin, Human Factors Engineering Branch.

REFERENCES

1. American Standards Association. **American Standard safety code for head, eye, and respiratory protection.** (Bulletin Z2.1-1959) New York: ASA, 1960.
2. American Standards Association, Subcommittee on Transmissive Properties of Plastics. **The spectral-transmissive properties of plastics for use in eye protection.** New York: ASA, 1955.
3. Blackwell, H. R. Contrast thresholds of the human eye. **Journal of the Optical Society of America,** 1946, 36, 624-643.
4. Bredemeyer, H. G., Wiegmann, O. A., Bredemeyer, A., & Blackwell, H. R. Radiation thresholds for chorioretinal burns. **USAF Aerospace Medical Research Laboratory Technical Documentary Report** No. AMRL-TDR-63-71, 1963.
5. Corning Glass Works. **Color Filters Catalog CF-3.** Corning Glass Works, Corning, N. Y., 1965.
6. Davson, H. (Ed.) **The eye. Vol. 1. Vegetative physiology and biochemistry.** New York: Academic Press, 1962. (a)
7. Davson, H. (Ed.) **The eye. Vol. 2. The visual process.** New York: Academic Press, 1962. (b)
8. DeMott, D. W., and Davis, T. P. Irradiance thresholds for chorioretinal lesions. **AMA Archives of Ophthalmology,** 1959, 62, 653-656.
9. DeValois, R. L., and Jacobs, G. H. Primate color vision. **Science,** 1968, 162, 533-540.
10. Duke-Elder, S. **Text-book of ophthalmology. Vol. VI. Injuries.** St. Louis: C. V. Mosby, 1954.
11. Dunn, K. L. A preliminary study on "glass-worker's cataract" exposures. **Industrial Ophthalmology,** Transactions, May-June 1950, 597-604.
12. Farnsworth, D. Standards for general purpose sun glasses. **USN Medical Research Laboratory Report** No. 140, Naval Submarine Base New London, Groton, Conn., 1948.
13. Fellows, B. J. Chance stimulus sequences for discrimination tasks. **Psychological Bulletin,** 1967, 67, 87-92.
14. Fine, B. S., Berkow, J. W., and Fine, S. Corneal Calcification. **Science,** 1968, 162, 129-130.
15. Geeraets, W. J. Retinal injury from lasers and other light sources. In H. G. Sperling (Ed.), **Laser eye effects.** Armed Forces-NRC Committee on Vision, April 1968, 20-56.
16. General Electric Company. **Spectral distribution for various temperatures of tungsten filament lamps.** Lamp Division, Applied Engineering Dept., Nela Park, 1953.
17. Graham, E. S., McVean, G. W., and Farrer, D. N. Near and far visual acuity in Rhesus monkeys (Macaca mulatta). **Perceptual and Motor Skills,** 1968, 26, 1067-1072.
18. Hays, W. L. **Statistics for psychologists.** New York: Holt, Rhinehart, and Winston, 1963.
19. Hogan, M. J., and Zimmerman, L. E. (Eds.) **Ophthalmic pathology.** (2nd ed.) Philadelphia: W. B. Saunders, 1962.
20. Illuminating Engineering Society. **IES lighting handbook.** (3rd ed.) New York: IES, 1962.
21. Johnson, F. S. The solar constant. **Journal of Meteorology,** 1954, 11, 99-104.
22. Kutscher, C. F. Ocular effects of radiant energy. **Industrial Ophthalmology,** July-August 1946, 15-26.
23. LeGrand, Y. Absorption of infrared by the human eye. (Sur l'absorption de l'infrarouge par l'oeil humain.) **C. R. Acad. Sci. Paris,** 1952, 234, 2228-2230. (**Psychological Abstracts,** 1953, 27, 4009.)
24. Lindquist, E. F. **Design and analysis of experiments in psychology and education.** Boston: Houghton Mifflin, 1953.
25. Luckiesh, M. Infrared radiant energy and the eye. **American Journal of Physiology,** 1919, 50, 383-398.
26. Luckiesh, M., and Moss, F. K. Infrared radiation and visual function. **Journal of the Optical Society of America,** 1937, 27, 69-71.
27. Lythgoe, R. J. **The measurement of visual acuity.** Special Report Series No. 173, Medical Research Council, H. M. Stationery Office, London, 1932.
28. Matthews, J. L. Physiological effects of reflective, colored, and polarizing ophthalmic filters. **USAF School of Aviation Medicine Report.** Project No. 21-02-040, Report No. 1. Randolph Field, Texas, 1949.
29. Mayer, H. L., and Richey, F. Eyeburn damage calculation for an exoatmospheric nuclear event. **Journal of the Optical Society of America,** 1964, 54, 678-683.
30. McDowell, R., and Brown, L. The effect of x-rays on the visual acuity of monkeys. **Journal of Genetic Psychology,** 1960, 96, 133-137.
31. Miller, J. W. (Ed.) **Visual problems of space travel.** Washington, D. C.: Armed Forces-NRC Committee on Vision, 1962.
32. Naval Medicine Research Institute. **An evaluation of evidence for injury to the eye by sunlight.** Bethesda: National Naval Medical Center, 1944. (**Abstracts on Military and Aviation Ophthalmology and Visual Sciences.** Vol. II. Washington, D. C.: Biological Sciences Foundation, 1953, No. 627.)
33. Prince J. H. (Ed.) **The rabbit in eye research.** Springfield, Ill.: Charles C. Thomas, 1964.

34. Rocco, R. M. Research and development of helmet face-pieces for space protective assemblies. AMRL-TR-66-193. AMRL, Aerospace Medical Systems Command, Wright-Patterson AFB, Ohio, January 1967.
35. Schilder, P., Pasik, P., and Pasik, T. Total luminous flux: A possible response determinant for the normal monkey. Science, 1967, 158, 806-809.
36. Sidley, N. A., Sperling, H. G., Bedarf, E. W., and Hiss, R. H. Photopic spectral sensitivity in the monkey: Methods for determining and initial results. Science, 1965, 150, 1837-1839.
37. Stair, R. Spectral-transmissive properties and use of eye-protective glasses. Circular 471, National Bureau of Standards, October 1948.
38. Verhoeff, F. H., and Bell, L. The pathological effects of radiant energy on the eye: An experimental investigation. Proceedings of the American Academy of Arts and Sciences, 1916, 51, 629-759.
39. Vos, J. J. A theory of retinal burns. Institute for Perception RVO-TNO, Report No. 1ZF 1959 6, Soesterberg, Netherlands, 1959.
(Tufts Bibliography, 1958-1959, No. 15174).

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* NAVAL SUBMARINE MEDICAL CENTER, Submarine Medical Research Laboratory	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
A PRELIMINARY INVESTIGATION OF THE EFFECTS OF NEAR INFRARED RADIATION ON VISUAL PERFORMANCE

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*
Kevin V. LAXAR

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
7 July 1969	34	39

8a. CONTRACT OR GRANT NO. b. PROJECT NO. M4305.08.3001D.04 c. Airtask No. A34531/562/69F32523401 d.	9a. ORIGINATOR'S REPORT NUMBER(S) SMRL Report Number 588 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Submarine Medical Center Box 600 Naval Submarine Base Groton, Connecticut 06340

13. ABSTRACT

Two Rhesus monkeys were trained on a visual form discrimination task. After training, test sessions were continued with near infrared radiation (0.8 to 3.5 microns), similar to solar spectral distribution and intensity, beamed into the subjects' eyes for a total of 20 hours exposure. Ocular examinations and retinal photographs before and after exposure to the infrared indicated no change. Comparisons of response rate and error rate between infrared and non-infrared condictions showed no significant differences. Evidence is presented for a possible avoidance response to the infrared radiation. Results indicate that 70 mw/cm^2 is a safe level of irradiance, and that the tinted plastic visors currently in use by U.S. Navy pilots afford sufficient eye protection from the sun's near infrared radiation, even at high altitude.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

3ND PPSO 13152

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Visual form discrimination						
Near Infrared Radiation effects						
Eye Protective equipment						
Infrared searchlights and signalling devices						