U.S. Naval Air Development Center

Johnsville, Pennsylvania

Aviation Medical Acceleration Laboratory

NADC-ML-6508 30 June 1965

Flashblindness: The Effects of Preflash Adaptation and Pupil Size

Bureau of Naval Weapons
WepTask RAE 13J 012/2021/R005 01 01
Problem Assignment No. J04AE23-1

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DEPARTMENT OF THE NAVY
U. S. NAVAL AIR DEVELOPMENT CENTER
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WARMINSTER, PA. 18974

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SUMMARY

A question of considerable operational importance is the extent to which the blinding effect of a flash from a nuclear weapon will vary with the ambient light level. Under conditions of darkness, the size of the pupil and the sensitivity of the eye are maximized. With an increase in the ambient light level both the sensitivity of the eye and the pupil size decrease. Data are presented on the independent effects of pupil size and receptor adaptation level on the production of flashblindness by high intensity, short-duration flashes.

CONCLUSIONS

It can be concluded from the results of this study that the blinding effect of a nuclear weapon flash will increase with the pupillary area. Thus, the larger pupillary area which normally accompanies low ambient illumination will increase significantly the flashblindness recovery times to all except very highly-illuminated displays. Within the limitations of this study, it also may be concluded that the preflash adaptation level is of little consequence in the problem of flashblindness except when a highly light-adapted observer must resolve a dimly-illuminated display following exposure to a nuclear weapon flash.

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INTRODUCTION

A question of considerable operational importance is whether the blinding effect of a nuclear weapon flash is less during the daylight hours than during the hours of darkness. Two changes which take place in the eye when the level of illumination changes are variations in the pupil size and in the sensitivity of visual receptors. Since the eye can function effectively over an extremely wide range of adaptation levels (2,7), and since preadapting luminances up to the level of bright sunlight are negligible compared with the total energy in a high-intensity flash, the contribution of the adaptation level existing prior to exposure to a high luminance flash would not be expected to affect significantly the recovery from the flash (4). Retinal illuminance varies directly with the pupil size, therefore the size of the pupil at the time of exposure to a high luminance flash would be expected to contribute to the recovery from the flash. In order to study the relationship between ambient light level and flashblindness recovery, the effects of pupil size must be separated from those of receptor adaptation level. The purpose of this study is to examine the blinding effect of a high-intensity flash as a function of pupil size and adaptation level.

APPARATUS AND PROCEDURE

A schematic drawing of the apparatus is shown in Figure 1. The apparatus enabled the experimenter to present to the observer a fixation point, a preadapting screen, an adapting flash, and an acuity test patch through a pupil of known diameter.

The fixation point, FP, a pinhole transilluminated with white light, was reflected by the unsilvered mirror, M_1, through the shutter, S_1, and the artificial pupil, AP, to the eye point, EP. The luminance of the fixation point was controlled by a potentiometer operated by the observer. The line of sight between the eye point and the fixation point was 22.5 inches. The observer's eye was held at the eye point with the aid of a dental impression bite board. The shutter, S_1, was closed between trials by the observer. When the observer was fixated on and accommodated to the fixation point, he closed the switch to begin the preflash adapting period.

The preadapting screen, SC, was white matte illustration board which, on light-adapted trials, was illuminated by two preadapting lights, PL, located on either side of and below the line of sight outside of the observer's field of view. The illumination of the preadapting screen was controlled by neutral density filters in filter boxes, F_2. The appropriate filters were placed in these filter boxes before each trial. The luminance of the screen was reflected by the first surface mirror, M_2, to the eye point.

The switch closed by the observer to begin the preflash adapting period also activated a timing circuit which caused a buzzer to sound for two seconds at the end of a 35-second preadapting period. Within the two-second period that the buzzer sounded, the filter box, F_2, was raised quickly by the experimenter into the line of sight where it was held by a solenoid-operated catch.

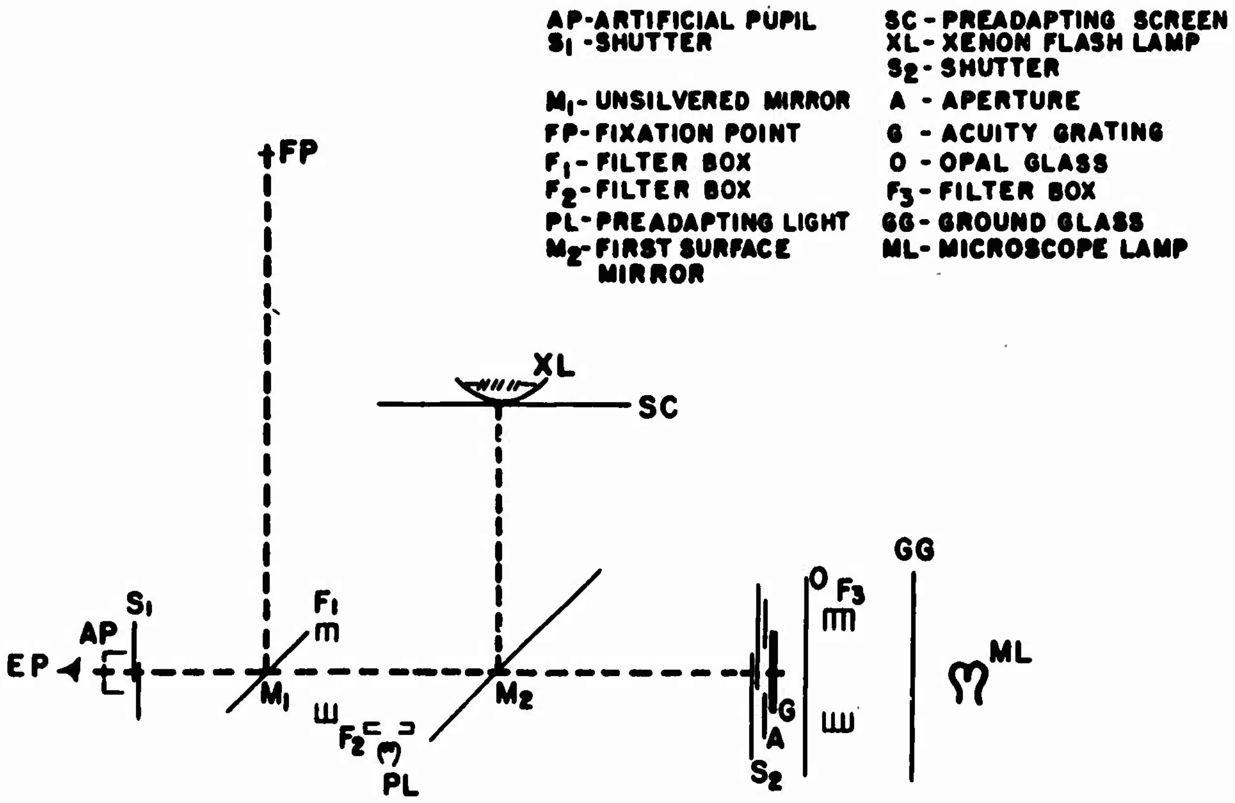

Figure 1. Schematic drawing of the apparatus.

As the filter box reached the end of its travel into the line of sight, it tripped a switch and activated the control circuits which ended the preadapting period, programmed the presentation of the adapting flash and the acuity test patch, and measured the time required by the observer to respond to the acuity test patch.

One control circuit activated by the switch tripped by the filter box, F_1, extinguished the preadapting lights, PL. A second circuit released the electromagnetic catch which held the preadapting screen in position perpendicular to the line of sight. The preadapting screen, hinged along one edge, then swung down out of the line of sight and exposed the xenon flash lamp, XL. As the adapting screen reached the end of its travel, it tripped a switch which caused the xenon lamp to flash. The flash was -3.8 log seconds in duration with a total luminance of 4.8 log mL seconds. The flash was reflected by the first surface mirror, M_2, through the filter box, F_1, to the eye point. The luminance of the flash was controlled by neutral density filters which were placed in the filter box, F_1, before each trial. The line of sight between the eye point and the flash lamp was 22.5 inches.

The first surface mirror, M_2, was hinged along one edge and held in position by an electromagnetic catch. The switch tripped by the fall of the adapting screen activated a delay circuit. After a delay of 100 milliseconds, this circuit released the electromagnetic catch and allowed the mirror, M_2, to fall. This delay circuit also released the solenoid-operated catch which held the filter box, F_1, and allowed it to fall. The fall of the mirror tripped a switch which opened the solenoid-operated shutter, S_2, exposed the acuity test patch, and started a timer to time the observer's response to the test patch.

The acuity test patch was limited by the circular aperture, A, which subtended one degree at the distance of 22.5 inches from the eye point. The acuity grating, G, which required an acuity of 0.33 for resolution, was directly behind the aperture and was transilluminated by light from the microscope lamp, ML, which was operated on direct current at 4.1 amperes. The light from the lamp was diffused by the ground glass, GG, and the flashed opal glass, O. The luminance of the test patch was varied by means of neutral density filters in filter box, F_3. The appropriate filters were placed in this filter box before each trial. A visual acuity of 0.33 was required to resolve the grating. The acuity grating could be rotated 90 degrees about its center axis so that the lines could be placed in vertical or horizontal position.

The acuity test patch, the flash lamp, and the fixation point were so arranged that the test patch and the brightest section of the tube of the flash lamp were imaged at the same location on the retina and the fixation point appeared at the right edge of the test patch. The preadapting screen filled the visual field which was limited 15 degrees by the aperture of the filter box, F_1.

The artificial pupil, AP, was one of two apertures in a slide fitted into the eye piece. The preadapting and adapting conditions were viewed through the first aperture, which was either 2, 5, or 7 millimeters in diameter, and the acuity test patch was viewed through the second aperture, which was always 2 millimeters in diameter. A ball detent positioned the first aperture of the slide for the adapting conditions, and a positive stop positioned the second aperture for the test condition. The observer pushed the slide as quickly as possible against the stop when the adapting flash occurred. The three slides used were keyed so that the appropriate artificial pupil size could be selected by touch in the dark. The natural pupil of the observer's right eye was dilated with 10 percent neo-synephrine ophthalmic solution to ensure that the artificial pupil was the limiting aperture.*

As soon as the observer was able to resolve the orientation of the acuity grating, he pressed a switch which stopped the timer and closed the shutter, S_2. The observer then indicated whether the grating orientation was horizontal or vertical. The experimenter checked the accuracy of the observer's report and recorded the duration of the exposure of the test patch. This procedure was reported at two-minute intervals until the end of the session.

The times required by the observer to respond to the acuity test patch were determined for three pupil sizes, five preadapting luminances, three display luminances and three adapting-flash integrated luminances. In addition, preliminary trials were run in which the integrated luminance of the adapting flash was -0.2 log millilambert-seconds. The preliminary trials were used as a control since any blinding effect it might produce would be insignificant, and the response times obtained would be attributable to the other experimental conditions.

Two observers were used in the study. Their vision was corrected to 20/20 by inserting the appropriate corrective lens into the eyepiece. Observer JHH had extensive experience as an observer in vision research. Observer WGS had limited experience as an observer.

RESULTS AND DISCUSSION

Before considering the experimental results of this study of the relation of pupil size and light adaptation level to the problem of flashblindness, the effects of these variables on visual acuity under normal conditions should be examined. The interrelations of light adaptation, test-patch retinal illumination, and visual acuity have been determined by Craik (2), and the interrelations of pupil size, retainal illumination and visual acuity have been determined by Leibowitz (5). In the latter study it was found that for a source of a given luminance, the log retinal illuminance and the log pupil area are linearly related with a slope constant of about 0.84. A curvilinear function was found to relate log visual acuity and log pupil diameter when the test-patch retinal illuminance was held constant. The optimal pupil diameter was found to be 2.77

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* The neo-synephrine opthalmic solution was administered under the direction of the project medical officer.

millimeters for test patches of low retinal illuminances and increased to about 4 millimeters for patches of high retinal illuminances. As the pupil diameter was increased from 2 to 5 millimeters the reduction in visual acuity amounted to no more than 0.15 log units. This loss in visual acuity is a result of the increase in dioptic aberrations with the increase in pupil size. The maximum variation occurred at low retinal illuminations and is less than the day-to-day variation found in some studies (5).

On the other hand, this same change in pupil diameter could produce almost a 0.7 log unit increase in the retinal illuminance obtained from a source of a given luminance. The possible change in visual acuity due to this resulting variation in retinal illumination is of more concern than that due to dioptic aberrations since it is in the opposite direction and could amount to more than 0.5 log units for poorly illuminated targets.

The variation in visual acuity with light adaptation level is somewhat more complex. For light adaptation levels below one effective foot candle, target luminances of from one to 1000 effective foot candles are equally effective. For target luminances above or below this range, however, visual acuity decreases for light adaptation levels of one effective foot candle or less. For adaptation levels above one effective foot candle, visual acuity decreases rapidly with a decrease in target luminance below the light adaptation level. The upper end of the range of effective target luminances increases with an increase in the light adaptation level (7).

In view of the above, the results of the preliminary trials shown in Figure 2 were to be expected. The summary tables of the analysis of variance of these data are given in Table 1. The significant effect of display luminance also was to be expected since response time varies with the luminance of the stimulus (3). Although both preadapting luminance and pupil size were statistically significant for observer WGS, the range of the mean response time for all conditions for each observer was less than 0.2 second.

The summary tables of the analysis of variance of the data collected under the experimental conditions of this study are given in Table 2. The significant effect of display luminance, flash luminance, and the interaction between them corroborates previous results (1,3).

The overall effect of pupil size on recovery time for all conditions is shown in Figure 3. An increase in pupil size from 2 mm to 7 mm increased the average recovery time by about 0.5 log units for both observers. The plots of recovery time as a function of pupil size and display luminance, Figure 4, show that an increase in display luminance of almost a log unit is required to compensate for the effects of a 7 mm pupil as compared with a 2 mm pupil. This effect is proportional to the pupilary area. These results show that pupil size has a practical and a statistically significant effect on flashblindness recovery time.

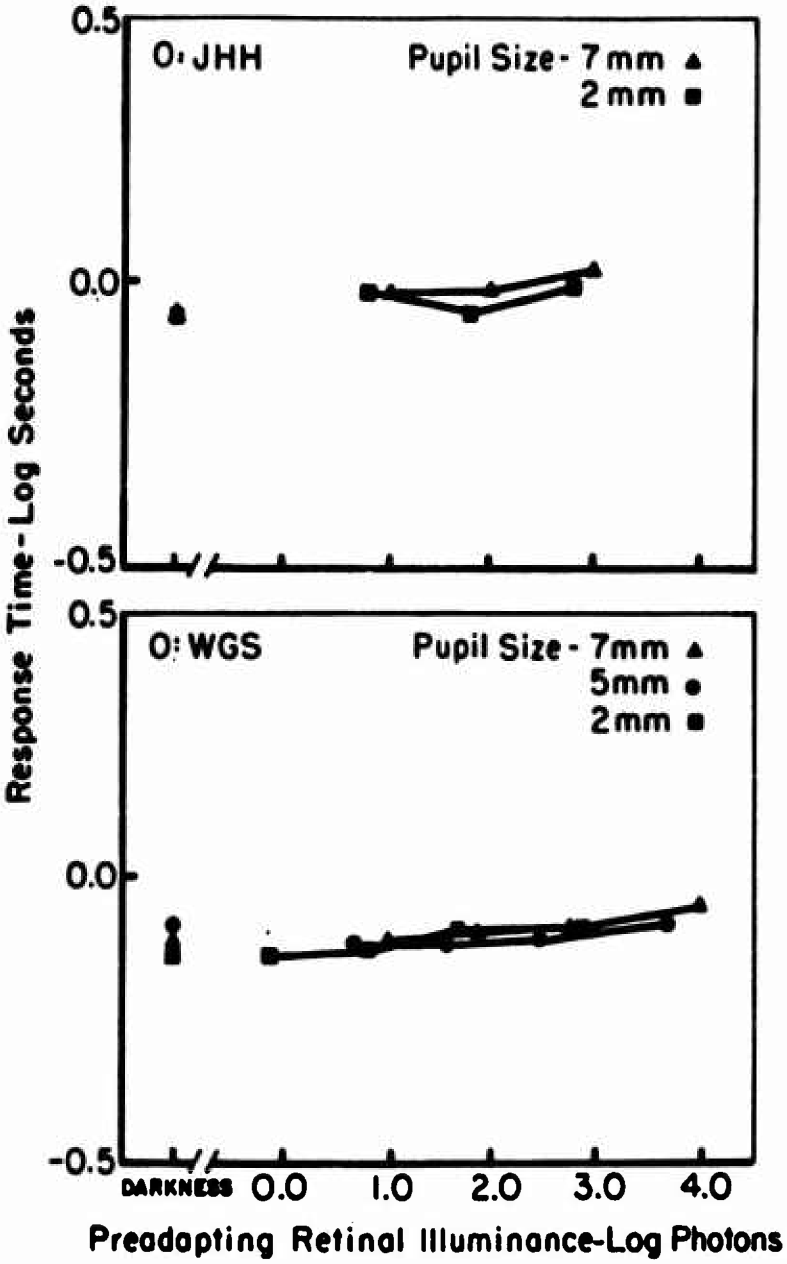

Figure 2. Preliminary trials - Response time as a function of preadapting retinal illuminance.

TABLE 1
ANALYSIS OF VARIANCE
SUMMARY TABLE
PRELIMINARY TRIALS

	Observer JHH		Observer WGS	
Source of Variance	df	F	df	F
Preadapting Luminance (A)	3	2.30	4	6.75*
Pupil Size (B)	1	0.87	2	6.25*
Display Luminance (C)	2	6.74*	2	5.00*
A x B	3	0.26	8	1.75
A x C	6	2.09	8	0.75
B x C	2	2.17	4	0.50
A x B x C	6	0.48	16	0.75
Error	48		90	

*$P < 0.01$

TABLE 2
ANALYSIS OF VARIANCE
SUMMARY TABLE
PRELIMINARY TRIALS

	Observer JHH		Observer WGS	
Source of Variance	df	F	df	F
Preadapting Luminance (A)	3	0.63	4	1.85
Pupil Size (B)	1	348.94*	2	332.73*
Display Luminance (C)	2	207.23*	2	1006.92*
Flash Luminance (D)	2	213.44*	2	621.05*
A x B	3	0.89	8	1.51
A x C	6	0.90	8	0.91
A x D	6	0.68	8	0.34
B x C	2	96.00*	4	77.75*
B x D	2	85.24*	4	32.63*
C x D	4	54.41*	4	150.96*
A x B x C	6	0.49	16	0.94
A x B x D	6	0.50	16	0.88
A x C x D	12	1.11	16	0.64
B x C x D	4	27.59*	8	10.00*
A x B x C x D	12	0.69	32	2.61*
Error	288		540	

*P < 0.01

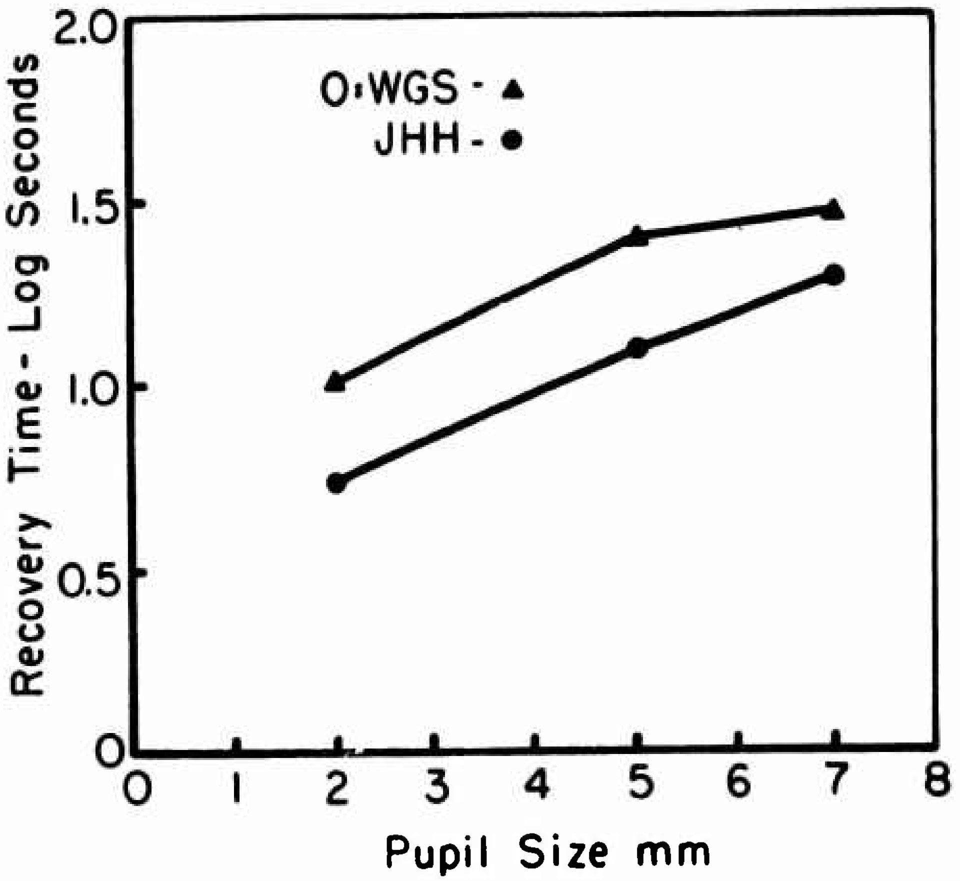

Figure 3. Flashblindness recovery time as a function of pupil size.

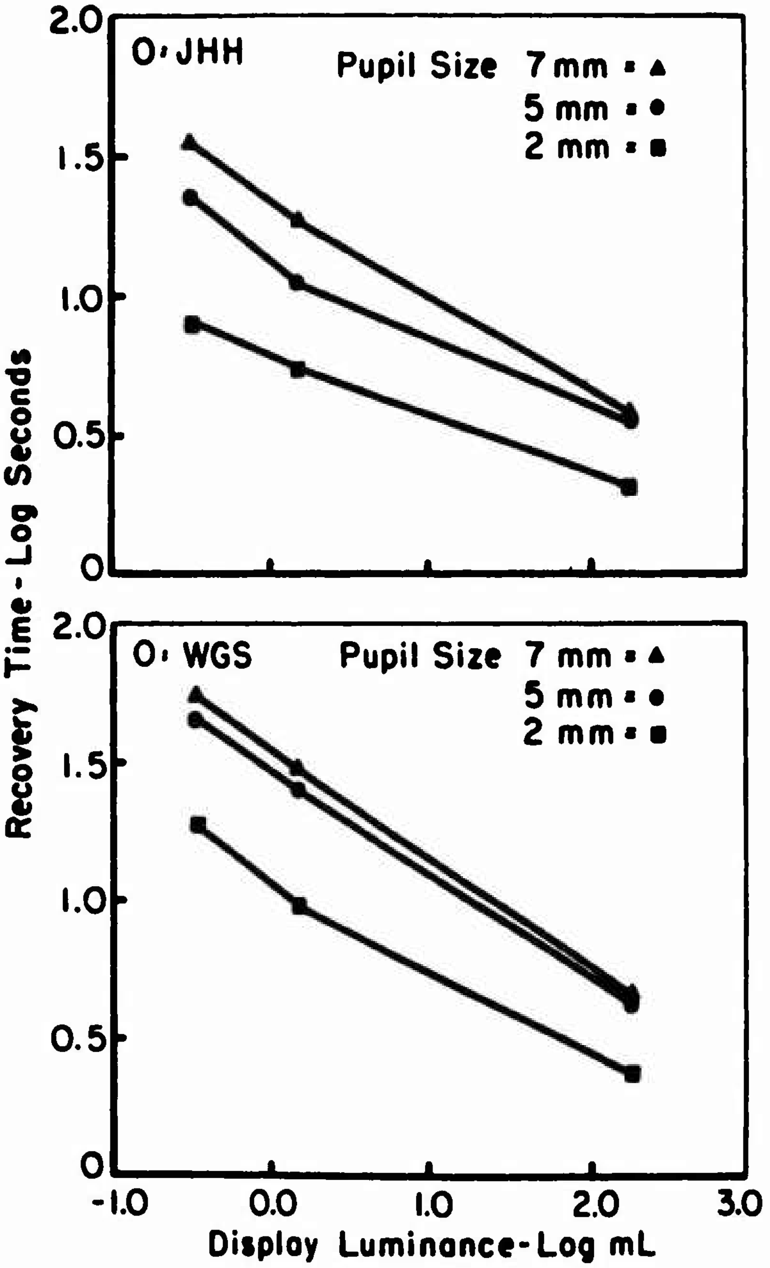

Figure 4. Flashblindness recovery time as a function of pupil size and display luminance.

The reason for the significant interaction between pupil size and display luminance also can be seen in Figure 4. At higher display luminances the effect of pupil size is reduced. This result is based on the significant interaction between flash luminance and display luminance, since a decrease in pupil size is effectively the same as a reduction in flash luminance proprotional to the decrease in pupillary area.

The plots of recovery time as a function of adapting flash luminance and pupil size are shown in Figure 5. The variation in the effect of pupil size with adapting flash luminance can be seen in these plots. This variation may account for the statistically significant triple interaction. It is of little practical significance, however, since the effect was in opposite directions for the two observers.

Although preadapting retinal illuminance had a statistically significant effect on the results of the preliminary trials, it produced no significant effect on the results of the experimental trials. Recovery time as a function of pupil size and preadapting retinal illuminance is shown in Figure 6. The little variation that did occur probably accounts for the statistical significance of the quadruple interaction, but it is certainly of no practical consequence. Thus, with respect to the preflash adaptation level of the eye, the high sensitivity of the dark-adapted eye does not increase the flashblindness recovery time.

It should be pointed out that a highly light-adapted eye exposed to a nuclear weapon flash might require a longer time to resolve a low luminance target than a similarly exposed dark-adapted eye. That this is indeed the case is indicated by results obtained by Miller (6) who found that for the resolution of a low luminance display, flashblindness recovery time increased at high preflash light adaptation levels; however, resolution times without exposure to a high-intensity flash were not reported.

CONCLUSIONS

It can be concluded from the results of this study that the blinding effect of a nuclear weapon flash will increase with the pupillary area. Thus, the larger pupillary area which normally accompanies low ambient illumination will increase significantly the flashblindness recovery times to all except very highly-illuminated displays. Within the limitations of this study, it also may be concluded that the preflash adaptation level is of little consequence in the problem of flashblindness except when a highly light-adapted observer must resolve a dimly-illuminated display following exposure to a nuclear weapon flash.

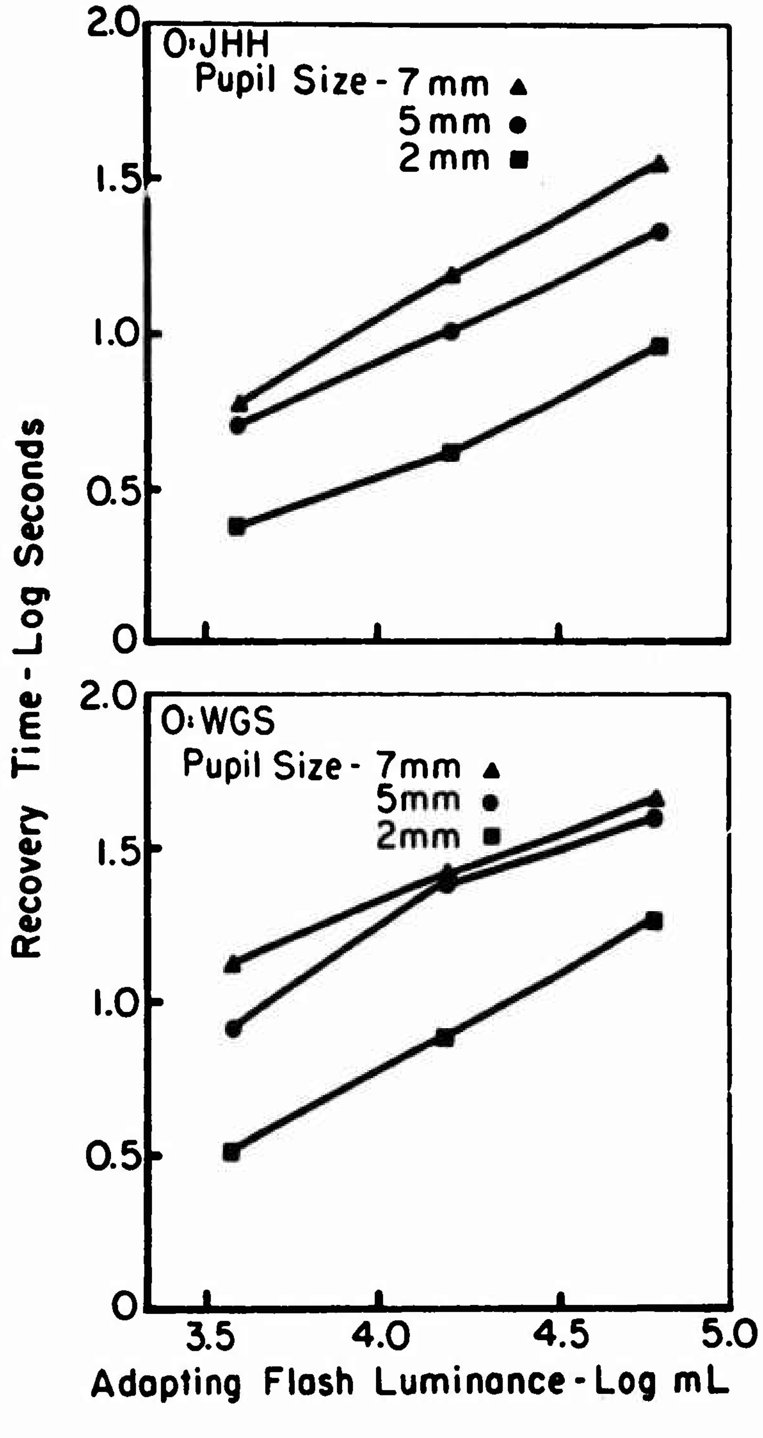

Figure 5. Flashblindness recovery time as a function of pupil size and adapting flash luminance.

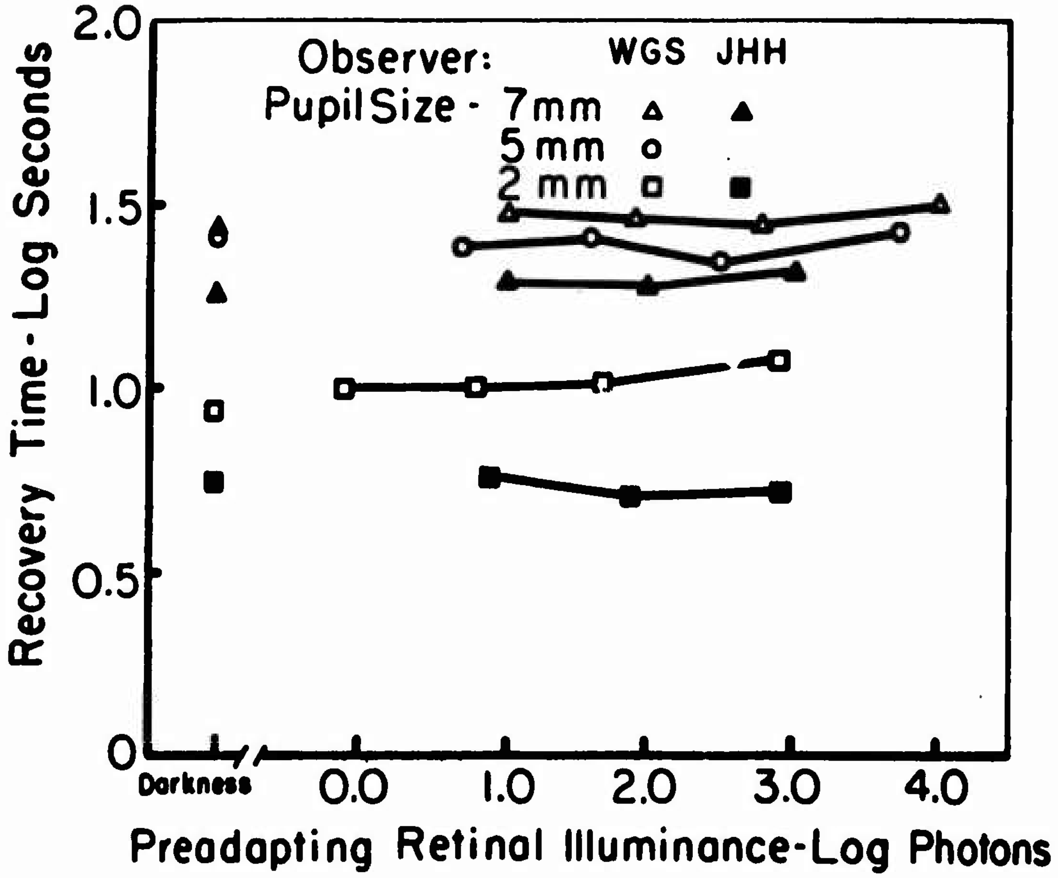

Figure 6. Flashblindness recovery time as a function of preadapting retinal illuminance and pupil size.

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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)*
U.S. Naval Air Development Center
Aviation Medical Acceleration Laboratory
Johnsville, Warminster, Pa. 18974

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
FLASHBLINDNESS: THE EFFECTS OF PREFLASH ADAPTATION AND PUPIL SIZE.

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

5. AUTHOR(S) *(Last name, first name, initial)*
Hill, J. H.
Chisum, Gloria T.

6. REPORT DATE
30 June 1965

7a. TOTAL NO. OF PAGES
14

7b. NO. OF REFS
7

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. WepTask RAE 13J 012/2021/
R005 01 01, Problem Assignment No.
c. J04AE23-1

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
NADC-ML-6508

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

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11. SUPPLEMENTARY NOTES

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DD FORM 1 JAN 64 1473

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Flashblindness						
2. Adaptation						
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