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EFFECT OF THE NEUTRAL DENSITY HELMET VISOR ON THE VISUAL ACUITY OF NAVY FIGHTER PILOTS

P. V. Hamilton and A. Morris

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Volunteer subjects were recruited, evaluated, and employed in accordance with the procedures specified in Department of Defense Directive 3216.2 and Secretary of the Navy Instruction 3900.39 series. These instructions are based upon voluntary informed consent and meet or exceed the provisions of prevailing national and international guidelines.

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The visual acuity of 63 Navy fighter pilots was measured under four viewing conditions in an Automated Vision Test Battery housed in a Mobile Field Laboratory operated by the Naval Aerospace Medical Research Laboratory (NAMRL). These and other pilots were also interviewed concerning their visor usage habits. Use of the 12% neutral density visor resulted in an average acuity loss of about 0.51 minutes of visual angle (mva) for low contrast targets under high-luminance laboratory conditions. The visor may cause an operationally significant reduction in visual acuity in the presence of luminance levels encountered at typical flight altitudes. Pilots range widely in their sensitivities to reduced contrast and glare, so a single optical density visor would not be optimal for many pilots. Pilot attempts to identify individually-optimal strategies for using visors and sunglasses often have no objective or systematic basis. Recommendations are presented for improving the vision of aviators wearing visors.

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FOREWORD

The present report is one in a series presenting data collected from U.S. Navy fighter pilots in training at the Air Combat Maneuvering Range, NAS Oceana, VA. The principle objective of the project is to relate visual and biographical parameters to air-to-air target detection and other measures of flying performance. The project has been supported by Naval Air Systems Command and the Naval Medical Research and Development Command.

SUMMARY PAGE

THE PROBLEM

The U. S. Navy stocks a single neutral density helmet visor for aviators flying cockpit-type aircraft. The Military Specification (MILSPEC) for this visor (MIL-V-85374-AS) requires it to transmit 12% ± 4% of visible light. The MILSPEC was developed over 25 years ago. As noted by the Commodore of FITWING ONE, it would be desirable to know the effect of the visor on aviator vision, and whether the visor characteristics and use might be improved.

THE FINDINGS

The visual acuity of 63 Navy fighter pilots was measured under 4 viewing conditions in an Automated Vision Test Battery housed in a Mobile Field Laboratory operated by the Naval Aerospace Medical Research Laboratory (NAMRL). These and other pilots were also interviewed concerning their visor usage habits. Use of the 12% neutral density visor resulted in an average acuity loss of about 0.51 minutes of visual angle (mva) for low contrast targets under high-luminance laboratory conditions. The visor may cause an operationally significant reduction in visual acuity in the presence of luminance levels encountered at typical flight altitudes. Pilots range widely in their sensitivities to reduced contrast and glare, so a single optical density visor would not be optimal for many pilots. Pilot attempts to identify individually-optimal strategies for using visors (and sunglasses) often have no objective or systematic basis. A research plan is recommended for improving the vision of aviators wearing visors.

RECOMMENDATIONS

1. Determine visual sensitivity to glare and visual contrast loss for aviators typically operating in bright, high-altitude sky environments.

2. Label specific visible transmission on helmet sun visors within the MILSPEC tolerances of 12% ± 4%. Techniques have been developed and transmission measurements are now performed in standard manufacturing processes of quality control.

3. With a range of visor densities available and visual glare sensitivity identified, offer pilots a choice of visors appropriate to their needs for best vision and comfort.

4. Collect additional information on the current use and instructions for use of the sun visor to provide recommendations for optimal visual performance.

5. Through laboratory research investigations, determine luminance and optical filtering conditions for best visual detection and resolution to improve specifications of the helmet sun visor.

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We wish to thank the Commodore and pilots of FITWING ONE, NAS Oceana, VA, for their willing cooperation with this project. Also, special recognition is given to two former leaders of vision research at NAMRL: CAPT James Goodson, who was involved from 1970-1982 during the planning and developmental phases of the Vision Test Battery, and CDR William Monaco, who was involved from 1982-1985 during the data gathering phase of the project. Mr. Efrain Molina and Mr. Ed Richa, both of NAMRL, provided extensive engineering and technical support throughout the project. This report was improved by the critical comments of Drs. Thomas Anderson, James Marsh, Leonard Temme, and CDR James Brady.

INTRODUCTION

In high luminance conditions, many aviators wear neutral density (gray) or tinted filters over their eyes, either in the form of a helmet visor or sunglasses. The helmet visors worn by Navy fighter aviators may be clear or neutral density. The Navy has only one optical density available for the neutral density visor (transmittance of 12% ± 4%; MILSPEC MIL-V-85374-AS).

The origin of the 12% visor MILSPEC is uncertain. The Defense Logistics Agency states that the MILSPEC was prepared by the Naval Air Development Center (NADC), Warminster, PA. Dr. G. Chisum, a vision specialist at NADC, states that this MILSPEC is at least 20 to 25 years old, and she knows of no one who has the original data used to develop it (personal communication). Dr. S. Luria, a vision specialist at the Naval Submarine Medical Research Laboratory, New London, CT, states that the MILSPEC was developed by Dean Farnsworth and Helen Paulson at least 30 years ago (personal communication). Farnsworth is deceased; Paulson, who is retired, recalls that the 12% figure was derived from their studies on sunglasses. They examined sunglasses with light transmission ranging from 3% (used by German submariners) and 4% (Arctic snow goggles) to 25% (commercially sold sunglasses). Farnsworth (1948) concluded that sunglasses in the 10 to 12% range were appropriate for general use on ships or on the ground by naval personnel. The 12%-visor transmission MILSPEC for the aviation visor may have been established from Farnsworth's conclusion.

Transparent materials through which an aviator must see while flying an aircraft inevitably influence image quality (see review by Genco, 1984). At the suggestion of the Commodore of FITWING ONE, NAS Oceana, VA, we conducted a preliminary laboratory evaluation of the effect of the neutral density visor on vision. The visor's effect on acuity at a single high luminance is reported, the visor-use habits of pilots are summarized, the probable effect of the visor under normal flying conditions is discussed, and a research plan for improving the vision of aviators wearing neutral density visors is recommended.

SUBJECTS

Sixty-three Navy F-14 pilots were studied. The pilots were drawn from six operational squadrons in Fighter Wing ONE, NAS Oceana, VA, while they practiced air combat maneuvers on the Tactical Air Combat Training System (TACTS) range. Additional vision tests were administered to each pilot on the same day, and flying performance data on the TACTS range and elsewhere were obtained for each pilot during the same weeks. All of these data were collected as part of an extensive project aimed at identifying measures of visual skill predictive of flying performance in F-14 pilots. The 63 pilots in this study were a subset of the 163 pilots involved in the entire project.

All of the pilots were male Caucasians ranging in age from 24 to 44 years, with a mean age of 29.3 years. The light transmitted by the helmet visor worn by each pilot was measured using a photometer (SPECTRA Spotmeter Model UBD 1/2°), corrected to the photopic spectral sensitivity curve. Nine of the 63 pilots wore prescription spectacles when they flew during the day, and these pilots were tested wearing their spectacles. The helmet visor was pulled down over the spectacles for the glare-with-visor test. These pilots were part of a group of 126 fighter aviators (121 pilots, 5 Range Information Officers) assigned to FITWING ONE who were interviewed regarding visor-use habits and problems.

VISION TESTS AND EXPERIMENTAL PROCEDURES

The vision tests were administered under controlled illumination using the automated Vision Test Battery (VTB) contained in a Mobile Field Laboratory located at NAS Oceana. The optical projectors and other test equipment were operated by an HP 9825 digital controller and microprocessors. Details of the vision test hardware are presented elsewhere (Morris and Goodson, 1983a; Molina, 1983, 1984).

All vision tests included in this report had the following features in common:

1. Tests involved binocular foveal acuity of subjects whose head position was fixed through use of a chin/brow rest.

2. The flat background screen was located at a far distance (5.5 m). Its luminance was 343 cd/m^2 (100 ft-L), which is about four times greater than used in clinical eye lanes.

3. Landolt-C targets (gap width one-fifth of the height) were centrally presented and were preceded by a fixation pattern. Stimulus sizes (gap widths) were specified in minutes of visual angle (mva). Target exposure time was 3 sec.

4. The subject was required to indicate the gap orientation (up, down, right, or left) of a Landolt-C target, which was varied in size (and hence angular subtense) between trials.

5. Every test began with 10 practice trials.

6. Thereafter, 10 size-threshold estimates were obtained using the staircase (up-down) psychophysical method, requiring from 40 to 80 trials.

7. Forced-choice responses were registered with a joystick. The subject's choice and reaction time were recorded for each trial.

Additional details concerning the vision tests addressed in this report are described below. Further test details are available in Morris and Goodson (1983b) and Monaco et al. (1985).

<u>Static Acuity, High Contrast</u> - In this test, the luminance of the Landolt-C test target was 686 cd/m^2, thus giving a target-to-background contrast ratio of +1.0, or 100%. (The equation used was: Contrast = (Target minus Background)/Background.) The mean and standard deviation (mva) of the 10 threshold estimates were computed, along with the mean reaction time (sec) for the 10 correct-response trials associated with the 10 threshold estimates. This is referred to as the "threshold-stressed reaction time."

Static Acuity, Low Contrast - In this test, the luminance of the Landolt-C was 377 cd/m^2, thus giving a target-to-background contrast ratio of +0.1, or 10%. The mean and standard deviation (mva) of the 10 threshold estimates were computed, along with the mean threshold-stressed reaction time.

Static Acuity, Low Contrast With Glare - In this test, a rear-projection, back-lighted diffuser screen was located 45.7 cm in front of the subject in the inferior (lower) half of his visual field. The screen's angular size was 15.5 deg vertical and 53 deg horizontal. The subject's line of sight to the test target on the far screen was 3 deg above the near diffuser screen. The veiling glare produced by the near diffuser screen yielded a luminance of 2800 cd/m^2, as measured at the subject's eye position with the photometer and cosine receptor attachment. The subject was instructed to refrain from squinting and to maintain constant fixation on the far test screen. The glare source was turned on, and the acuity test began after 2 min of adaptation. The glare source was not directly viewed, nor did the glare illumination strike the far target screen. Thus, the target-to-background contrast remained at 10%. Several subjects commented that the test conditions realistically simulated the glare conditions encountered when flying above cloud or snow fields. The mean and standard deviation (mva) of the 10 threshold estimates were computed, along with the mean threshold-stressed reaction time. This was the last test performed on each subject, so the effects of glare exposure did not influence results from other tests.

Static Acuity, Low Contrast With Glare and Visor - In this test, the glare source and target-to-background contrast were maintained as described above, but the subject wore his helmet with the standard '12%-transmission' helmet visor down. The mean and standard deviation (mva) of the 10 threshold estimates were computed, along with the mean threshold-stressed reaction time.

All data were stored at a mainframe computer facility and manipulated and analyzed using the Statistical Analysis System (SAS). The significance level applied in all statistical tests was 0.05.

RESULTS

For the group of 63 pilots, static visual acuity thresholds and threshold-stressed reaction times progressively degraded with reduced contrast, with the addition of glare, and with the addition of the visor in the presence of glare (Table 1). Visual acuity degraded from 0.41 mva (20/8 Snellen) for high contrast targets to 1.63 (20/33 Snellen) for low contrast targets with glare and the visor present. Threshold-stressed reaction times degraded (increased) from 1.36 sec for high contrast targets to 1.99 sec for low contrast targets with glare and the visor present. Frequency distributions for static acuity threshold means and threshold-stressed reaction times are shown in Figure 1 for the different viewing conditions. The curves in Figure 1 were obtained by rounding off acuity (to 0.05 of log-10 mva) and reaction time (to 0.15 sec) values, by computing the frequency of occurrence for each rounded value, by computing 4th-order polynomials to fit the points described by the frequencies and the rounded values, and by plotting the central peaks of these polynomial functions.

Additional vision measures were derived for each subject from his original data: decrement in acuity due to reduced contrast (threshold at high contrast minus threshold at low contrast), decrement in acuity due to glare (threshold at low contrast minus threshold at low contrast with glare), and decrement in acuity due to visor (threshold at low contrast with glare minus threshold at low contrast with glare and visor). In other words, the more negative the decrement value, the greater the decrement. Positive values of the decrement variables indicate an improvement rather than a decrement in acuity. Distributions for these acuity threshold decrement variables are shown in Figure 2.

The mean decrement in acuity due to reduced contrast was -0.44 mva (range: -0.11 to -1.31); the mean decrement in acuity due to the presence of glare was -0.27 mva (range: +0.28 to -1.48); and the mean decrement in acuity due to the use of the visor was -0.51 mva (range: +0.96 to -1.89). In all three cases, the mean acuity decrement values were significantly different from zero (Student's $t > 7.5$, $\underline{p} < 0.001$). None of the 63 pilots exhibited improved acuity with reduced contrast. However, seven pilots (11%) exhibited improved acuity when glare was added, and three pilots (5%) exhibited improved acuity when the visor was used in the presence of glare. Although the subjects were instructed not to squint, inconspicuous tightening of the eyelids around the eyes, in response to the bright glare, could have been responsible for the improved acuity of some pilots in the presence of glare.

Decrements in threshold-stressed reaction time were also computed, following the same pattern as was used for the acuity decrement variables. The mean decrement in threshold-stressed reaction time due to reduced contrast was -0.30 sec (range: +0.46 to -1.00); the mean decrement in threshold-stressed reaction time due to the presence of glare was -0.04 sec (range: +1.19 to -0.94); and the mean decrement in threshold-stressed reaction time due to the use of the visor was -0.28 sec (range: +0.80 to -1.15). Eleven of the pilots (17%) exhibited improved (shorter) threshold-stressed reaction times with reduced contrast; 24 of the pilots (38%) exhibited improved reaction times with the addition of glare; and 18 of the pilots (29%) exhibited improved reaction times with use of the visor.

Analysis of correlations between acuity thresholds and acuity threshold decrements (Table 2) indicate that the thresholds all have significant positive intercorrelations. A significant positive correlation exists between contrast decrement and visor decrement. The significant negative correlation between glare decrement and visor decrement is the result of a single outlier; with this subject excluded, the correlation was not significant. Analysis of correlations between threshold-stressed reaction times and decrements in threshold-stressed reaction times (Table 3) indicates that the threshold-stressed reaction times all have significant positive intercorrelations. We found no clear pattern in the relationships among the decrements in threshold-stressed reaction time.

No significant correlations existed between pilot age and any of the vision measures for the sample group reported herein. Similarly, no statistically significant differences existed between spectacled and non-spectacled pilots in any of the vision measures reported here. Morris and Hamilton (1986) found significant age and spectacle-related visual differences in a larger group of fighter pilots, which included these subjects.

The mean visor transmission measurement was 11.31%. Only 2 of the 63 visor transmission measurements were out of the MILSPEC range, which is 12% ± 4%; 1 visor measured 7.0% and the other measured 19.1%. A distribution of the visor transmission data is presented in Figure 3.

In order to determine if the visor-use habits of pilots during general flight were associated with their individual glare sensitivities, interview data for 126 fighter pilots were categorized and compared with their acuity decrements due to glare (Table IV). (Glare sensitivity data for all 126 pilots were available in the project data base.) An analysis of variance indicated no significant differences in the acuity decrements due to glare among the three visor-use categories ($F = 0.46$). Twenty-seven of the 126 pilots described themselves as 'glare sensitive.' The mean acuity decrement due to the presence of glare for these 27 pilots was -0.35 mva, as compared to -0.22 mva for the remaining 99 pilots. Student's t-test found these differences marginally significant ($t = 1.976$, adjusted $df = 32.6$, $p = 0.0567$). As shown in Table IV, most of the 27 'glare sensitive' pilots indicated that they always wore their visor. The two groups of pilots did not differ significantly in age or any other vision measure.

The absence of a stronger relationship between visor-use habits and objective measures of visual function suggests that visor use during general flight is influenced by other factors. Pilot interviews suggest that visor-use preference may be influenced by squadron policy, peer opinions, the opinion of a flight instructor involved in the pilot's early training, or whatever the pilot finds comfortable. Two pilots described an ongoing search for the right visor/sunglasses condition for themselves. Eleven pilots wore sunglasses in-flight; five wore neutral fixed-density sunglasses, two wore amber fixed-density sunglasses, one wore amber variable-density (i.e., photosensitive) sunglasses, and three wore neutral variable-density sunglasses. Two pilots wore variable-density sunglasses beneath the visor. One pilot used a gold visor obtained privately. Eighteen of the pilots indicated that they never used the visor when they needed to see well, such as when searching for bogeys on the TACTS range. Several pilots expressed a wish to have visors available with other optical densities than the single density (12% transmission) currently stocked, so that they could select which one was installed in their helmet. Collectively, the information reveals considerable variation in visor use habits among pilots, some dissatisfaction with the currently available visor, a general lack of objectivity in developing visor usage habits, and a variety of approaches for determining optimal visual aids.

DISCUSSION

Visual Acuity and Luminance

The ability to see a target clearly is influenced by numerous features of the target, the environment, and the eye. For the subjects studied here, both acuity and threshold-stressed reaction time degraded with reduced contrast, the addition of veiling glare, and the neutral density visor placed in front of the eyes. This effect is evidenced in increases in both threshold and variance (Figure 1).

In general, acuity progressively improves with increased target-to-background contrast and with increased accuracy of accommodation. A more complex relationship exists, however, between acuity and ambient illumination (see Figure 4). As noted by Daumann (1982), acuity is optimal at a luminance of about 1100 cd/m^2, and is progressively poorer at both higher and lower luminances. This relationship must be due, at least in part, to the effects of pupil diameter on image quality. Borish (1975) reviewed several studies that indicate that diffraction progressively limits acuity for pupil diameters less than 2 mm, and aberrations progressively limit acuity for pupil diameters over 3 mm. Two of the eight studies reviewed by De Groot and Gebhard (1952) measured pupil diameters at luminances up to 3,000 cd/m^2, and these studies found that a pupil diameter of 2.5 mm was exhibited at about 1,000 cd/m^2, which is about the luminance level for optimal acuity (see Fig. 4). Leibowitz (1952) showed that acuity was optimal for an artificial pupil diameter of about 2.5 mm. The curve in Figure 4 reflects general optical and physiological influences on visual functioning, so the idea of a single luminance for optimal vision is undoubtedly applicable to most viewing conditions and measures of visual performance. The optimal luminance probably varies somewhat with the viewing conditions and visual task involved.

As the visual function curve indicates, the effect that a 12% visor will have on acuity will depend on the ambient light level. At some illuminances, a 12% visor would improve acuity, while at other illuminances the 12% visor would reduce acuity. Thus, a critical question to be answered is: How close to the luminance level for optimal acuity does the standard helmet visor bring an aviator who is exposed to illumination levels that are operationally realistic?

Operational Luminance and Performance

Values for operationally realistic luminances depend on solar illuminance, optical characteristics of the atmosphere, and direction of view. Tousey and Hulburt (1947) reported that mid-day solar illumination levels at 10,000 feet may be as high as 12,000 ft-candles. This corresponds to a luminance of about 2.2 billion cd/m^2 for someone looking straight into the sun. Sliney and Freasier (1973) gave a value of 1.7 billion cd/m^2, which is presumably for direct viewing of the sun from ground level. However, most of a pilot's visual scanning is not directed straight toward the sun. More realistic luminance measures would be based on fields of view in or near the horizontal direction. Representative mid-day luminance data are provided by Boileau (1964), based on a clear day in February in Florida. At an altitude of 20,000 ft, the average luminance for all azimuths at a zenith angle of 90° (i.e., horizontal) was about 7,500 cd/m^2; the average luminance for all azimuths at a zenith angle of 80° (i.e., 10° above the horizon) was about 3,440 cd/m². Farnsworth (1948) cited sky luminances as seen from a plane (altitude unspecified) on a clear day looking away from the sun between 3,400 and 6,800 cd/m².

If one accepts values between 3,400 and 7,500 cd/m² as a realistic range of luminances encountered by aviators flying cockpit-type aircraft at normal operational altitudes, then the 12%-transmission visor would expose the eyes to luminances in the range from 408 to 900 cd/m². Thus, according to the curve in Figure 4, the acuity of these aviators would be about 5% sub-optimal. The acuity of aviators wearing visors near the 8% end of the acceptable MILSPEC range would be about 10% sub-optimal. Hence, this analysis suggests that the 12% visor passes insufficient light for optimal acuity at operationally realistic luminances (i.e., it is too dark). It is interesting to note that the U. S. Army and the U. S. Air Force helmet visor MILSPEC total visible transmittance is 15% ± 3%. (Personal communications Dr. J. Crosley, USAARL, Ft. Rucker, AL, and LTCOL R. J. Dennis, USAFSAM, Brooks AFB, TX.)

The effect of even a small difference in acuity on visual performance is commonly underestimated. If a pilot's ability to detect an aircraft target is primarily a function of high-contrast acuity, then a difference in acuity can be expressed in terms of the difference in maximum slant range at the instant a target aircraft can be visually detected. On the TACTS range, the average fighter aircraft exposes a silhouette of about 250 square feet to an adversary. The farthest distance that a pilot with an acuity of 0.4 mva or 20/8 Snellen (the average in Table 1) would <u>theoretically</u> be able to detect this aircraft visually would be 25.2 nautical miles (nm). However, a pilot with an acuity of only 0.5 mva or 20/10 Snellen would not be able to detect the aircraft visually until it was 20.2 nm away. Thus, the 0.1 mva acuity difference results in a theoretical 5 nm tactical disadvantage. For a low contrast target with 2800 cd/m² of glare present (i.e., for conditions comparable to those maintained during the relevant laboratory tests), the farthest distance that the average pilot with his visor up (not in use) would theoretically be able to detect the same target aircraft would be 8.0 nm, but with his visor down (in use) he would not be able to detect it until it was 6.2 nm away. In this situation, use of the visor would result in a 1.8 nm tactical disadvantage.

Variables such as target size, target-to-background contrast, and atmospheric effects would influence the distance values cited above, but not the basic argument, because the visor effect is superimposed on whatever viewing conditions exist. Also, the same argument would apply to other aircraft detection circumstances, such as in collision avoidance. Other examples of reduced range of visual detection due to aircraft windshields and other transparencies are given in Self (1973). Even slight visor imperfections can constitute additional sources of veiling glare (Clark, 1979), so reduced acuity through a visor may be due to more than just its optical density and reduced luminance. Increases in reaction time resulting from degraded stimulus conditions would also affect operational performance detrimentally, especially at high closing velocities.

While the above discussion suggests that the 12% visor may not allow optimal acuity at operationally realistic luminance levels, the specific numbers cited may not accurately represent the real situation, for several reasons. First, the curve in Figure 4 is for high-contrast (100%) acuity, but the contrast between target aircraft and the background is almost certainly lower, because of haze, camouflage patterns, etc. The optimal luminance for spot detection is probably different for different levels of target contrast with the background. Second, the curve in Figure 4 is for an average person. Because pilots vary so widely in the effects that glare and reduced contrast have on their acuity, the luminance corresponding to optimal acuity undoubtedly also varies widely among pilots. Thus, pilots would be expected to vary in the magnitude of visual decrement they experience when wearing the 12% visor at the same luminance; in fact, the data summarized in Figure 2C indicate that they do. Finally, prolonged exposure to high ambient luminances influences visual performance (Peckham and Harley, 1950, 1951). One luminance level may allow optimal vision for short exposures, but another luminance may be optimal for longer exposures (such as would occur during prolonged flights).

Two additional points should be recognized about the operational relevance of the luminance/visor transmission relationship. First, sighting target aircraft is a detection task, but identifying target aircraft is a resolution task; visor transmission would influence both visual functions, and both tasks are critical to tactical success. Spot detection and static acuity thresholds under fixed high contrast conditions are highly correlated for these pilots ($r = 0.52$, $n = 163$, $p < 0.0001$; Morris and Hamilton, 1986), but Lie (1981) has reported that detection and resolution tasks are influenced differently by luminance level. Hence, the influence of luminance on both spot detection ability and on acuity should be considered. Second, luminances encountered at 20,000 feet are not the same as those encountered on the ground. Ground luminance levels in the range of 10,000 to 15,000 cd/m^2 are quoted in the literature (Daumann, 1982; Luria, 1984). Boileau's (1964) data indicate an average luminance at 0 elevation for all azimuths at a zenith angle of 80° (i.e., 10° above the horizon) of about 9,000 cd/m^2. Thus, a visor that is optimal for flying at altitude may transmit too much light in the brighter environment of a runway. Conversely, sunglasses that are optimal on the ground, will transmit too little light at altitude. The historical origin of the 12% MILSPEC is apparently reflected by the latter example. Visual detection tasks in flight are more critical to the tactical aviator than those on the runway, so luminances at altitude should dictate optimum visor transmission.

Development of a Better Visor

The ideal solution to this luminance-dependent, visor transmission problem would be to develop a sensor-driven, variable-density visor. Such a visor system could instantaneously detect changes in ambient luminance, and adjust its transmission at a millisecond rate to allow the wearer to experience optimal vision. Also, such a visor system could presumably be tuned to match an aviator's personal level of glare sensitivity. Industrial optical engineers have experimented with quick-response, variable density visor materials, but manufacturing problems and costs have caused such designs to be abandoned as unfeasible.

Until technological advances allow production of an ideal visor, aviators will undoubtedly have to use fixed density visors. Given the apparent origin of the 12% MILSPEC, and the data and arguments presented here, re-evaluation of the 12% MILSPEC is recommended. Quantitative measurements should be obtained of low-contrast acuity, low-contrast spot detection ability, and contrast sensitivity for subjects who are exposed to an operationally realistic luminance, and whose eyes are covered by neutral density filters having a range of optical densities. Also, the effect of exposure time on these three visual functions should be assessed, for the different neutral density filters at the operationally realistic luminance level used. This process would identify the optical density of the neutral density filter that permits optimal visual functioning at the average luminance, for a realistic exposure time, for the average subject. The study should carefully discriminate between measures of ocular comfort and visual acuity. These two factors may be optimized with different filter densities, and so both of these factors may have to be considered when determining the operationally-optimal neutral density visor. Also, the study should consider how realistic operational factors such as physiological stress (e.g., due to fear or G-forces) and hypoxia might influence measurements and conclusions. Finally, any decision to increase visor transmission should include consideration of how such a change would affect night vision through long-duration influences on retinal sensitivity.

Completion of the above studies would lead to identification of the best average visor transmission for operational conditions, but the average visor would obviously not be optimal for all aviators. Individuals vary in their degree of glare sensitivity, and the Navy fighter pilots studied here are no exception. Their acuity decrements due to glare ranged from +0.28 to -1.48 mva, with 11% of the pilots actually demonstrating improved acuity with glare. A satisfactory alternative to stocking just one fixed-density visor would be to stock a series of fixed-density visors allowing different degrees of light transmission. Techniques for measuring percentage transmission of each visor are used to assure quality control and compliance with government MILSPEC tolerances. During production, the manufacturer could label each visor with its specific transmission, thus identifying and providing a range of densities from 8 to 16% transmission with a minimum of additional manufacturing effort. An aviator could then choose the visor transmission best suited to his personal degree of glare sensitivity. To provide an objective basis for choosing a visor in a particular transmission category, a glare disability test could be administered during the physical exam or at the same time an aviator receives a personal fit for his helmet and other items of flight equipment, such as parachute harnesses and oxygen masks. Since glare sensitivity increases with age (Wolf, 1960), it might be advisable to administer a glare disability test at regular intervals during an aviator's career.

An expansion of this research effort would be to evaluate sunglasses worn by aviators flying flight deck-type aircraft, and to identify the optimal optical density for such sunglasses. Luria (1984) recently used the general approach proposed above to evaluate the optimal optical density appropriate for sunglasses worn outdoors, under two conditions of illumination. In that study, the subjects rated different optical densities based on ocular comfort, and their acuity was also measured for different optical densities. In general, the sunglasses that were rated most comfortable were also those that allowed the best acuity. These sunglasses exposed the eyes to luminance levels between 1,000 and 1,400 cd/m^2. This is the same luminance level corresponding to the peak of the curve in Figure 4, and the same luminance level at which pupil diameter allows optimal image quality.

SUMMARY

In summary, data on F-14 pilots show that the 12% helmet visor causes a significant reduction in low contrast acuity under high-luminance laboratory conditions. Analyses suggest that this visor may also cause a significant reduction in visual functioning at operationally realistic luminances. Attempts by pilots to identify individually-optimal strategies for using visors (and sunglasses) are subjective and not systematic. A wide range of glare sensitivities and visor effects exists among Navy pilots, so dissatisfaction with the current "one optical density for all" approach is to be expected. The 12% transmission for the neutral density visors worn by naval aviators is at least 25 years old, and it was apparently determined by an inexact procedure. We recommend re-evaluation of the 12% MILSPEC.

RECOMMENDATIONS

1. Determine visual sensitivity to glare and visual contrast loss for aviators typically operating in bright, high-altitude sky environments.

2. Label specific visible transmission on helmet sun visors within the MILSPEC tolerances of 12% ± 4%. Techniques have been developed and transmission measurements are now performed in standard manufacturing processes of quality control.

3. With a range of visor densities available and visual glare sensitivity identified, offer pilots a choice of visors appropriate to their needs for best vision and comfort.

4. Collect additional information on the current use and instructions for use of the sun visor to provide recommendations for optimal visual performance.

5. Through laboratory research investigations, determine luminance and optical filtering conditions for best visual detection and resolution to improve specifications of the helmet sun visor.

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Table 1. Summary Statistics for Static Acuity of Navy Fighter Pilots (n = 63) Under Different Viewing Conditions.

Test	Threshold (mva)	Threshold-Stressed Reaction Time (sec)
High Contrast		
Mean	0.407 (20/8)*	1.362
SD	0.065	0.457
Low Contrast		
Mean	0.850 (20/17)*	1.663
SD	0.250	0.525
Low Contrast, With Glare		
Mean	1.121 (20/22)*	1.707
SD	0.389	0.454
Low Contrast, With Glare and Visor		
Mean	1.627 (20/33)*	1.988
SD	0.540	0.499

* Snellen acuity equivalents in parentheses.

Table 2. Correlation Matrix for Acuity Thresholds and Decrements in Acuity Thresholds for Different Targets and Viewing Conditions. The Data in Each Cell are Arranged as: Pearson Coefficient/ Significance Probability.

Acuity Threshold	Code	A	B	C	D	E	F	G
High contrast	A	–	0.7207 0.0001	0.5577 0.0001	0.4772 0.0001	-0.5523 0.0001	-0.1289 0.3139	-0.1124 0.3803
Low contrast	B		–	0.6724 0.0001	0.6897 0.0001	-0.9760 0.0001	-0.0421 0.7432	-0.2925 0.0200
Low contrast w/glare	C			–	0.6859 0.0001	-0.6333 0.0001	-0.7678 0.0001	0.0318 0.8048
Low contrast w/glare & visor	D				–	-0.6793 0.0001	-0.3289 0.0085	-0.7056 0.0001
Contrast decrement	E					–	0.0101 0.9374	0.3164 0.0115
Glare decrement	F						–	-0.2960 0.0185
Visor decrement	G							–

Table 3. Correlation Matrix for Threshold-stressed Reaction Times and Decrements in Threshold-stressed Reaction Times for Different Targets and Viewing Conditions. The Data in Each Cell are Arranged as: Pearson coefficient/Significance Probability.

Threshold-stressed Reaction Time	Code	A	B	C	D	E	F	G
High contrast	A	-	0.7957 0.0001	0.4023 0.0011	0.4162 0.0007	0.1220 0.3407	0.4888 0.0001	-0.0568 0.6584
Low contrast	B		-	0.5242 0.0001	0.4698 0.0001	-0.5040 0.0001	0.5967 0.0001	0.0083 0.9486
Low contrast w/glare	C			-	0.5780 0.0001	-0.2853 0.0234	-0.3706 0.0028	0.3769 0.0023
Low contrast w/glare & Visor	D				-	-0.1763 0.1669	-0.0323 0.8017	-0.5380 0.0001
Contrast decrement	E					-	-0.2809 0.0258	-0.0946 0.4610
Glare decrement	F						-	-0.3462 0.0055
Visor decrement	G							-

Table 4. Summary of Visor Use Interviews and Acuity Decrements Due to Glare for 126 Navy F-14 Pilots.

Frequency of Visor Use	Total Number of Pilots	Number of Pilots		Acuity Decrement due to Glare (Mean ± SD)
		'Glare Sensitive'	Wearing Sunglasses	
Never	14	0	8	-0.22 ± 0.14
Seldom	15	1	0	-0.26 ± 0.10
Sometimes	24	1	1	-0.28 ± 0.29
Usually	22	5	0	-0.19 ± 0.18
Always	51	22	2	-0.26 ± 0.31

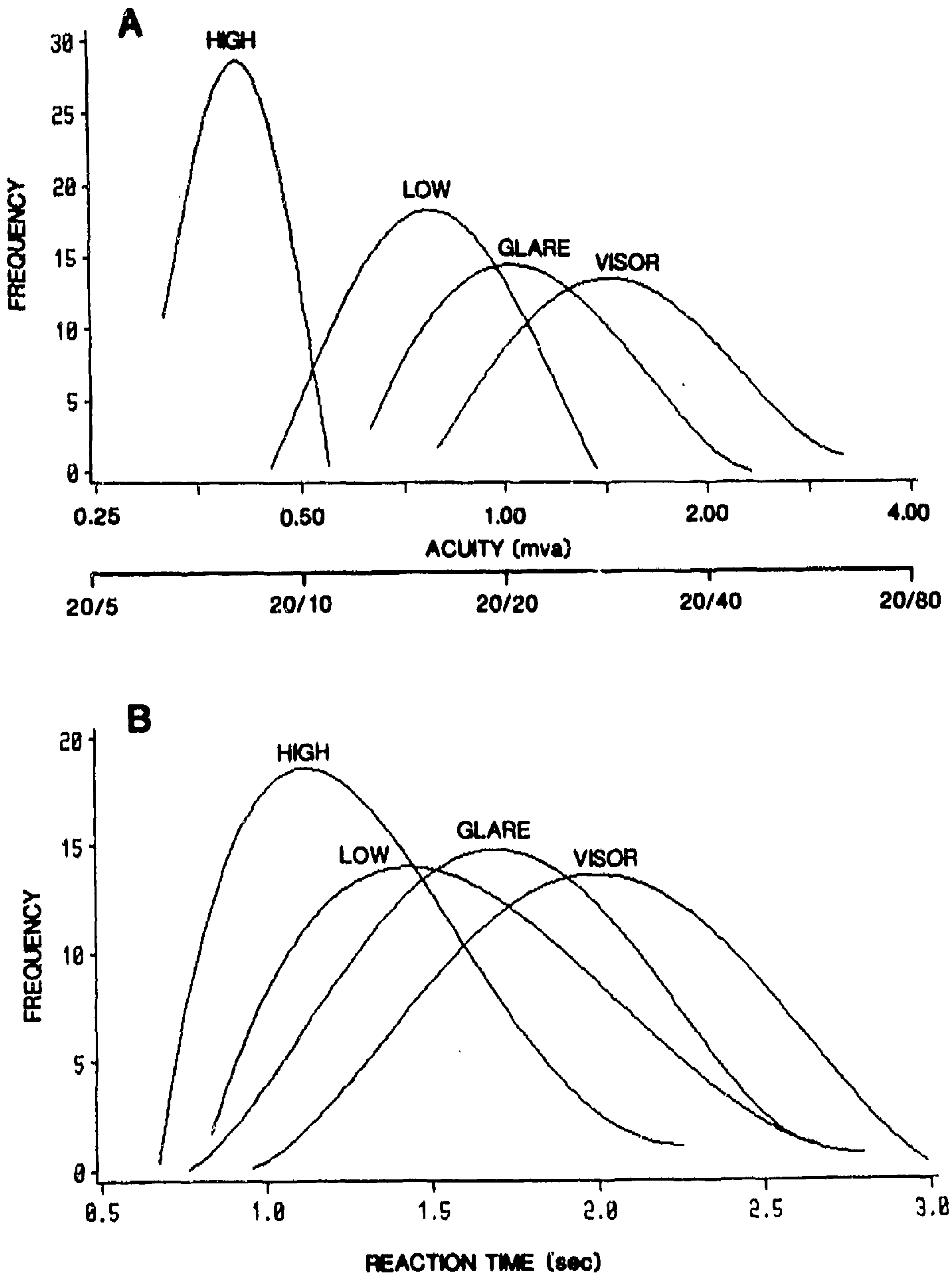

Figure 1. Frequency distribution for static acuity thresholds (A) and threshold-stressed reaction times (B) for high contrast targets (HIGH), low contrast targets (LOW), low contrast targets with glare (GLARE), and low contrast targets with glare and visor (VISOR).

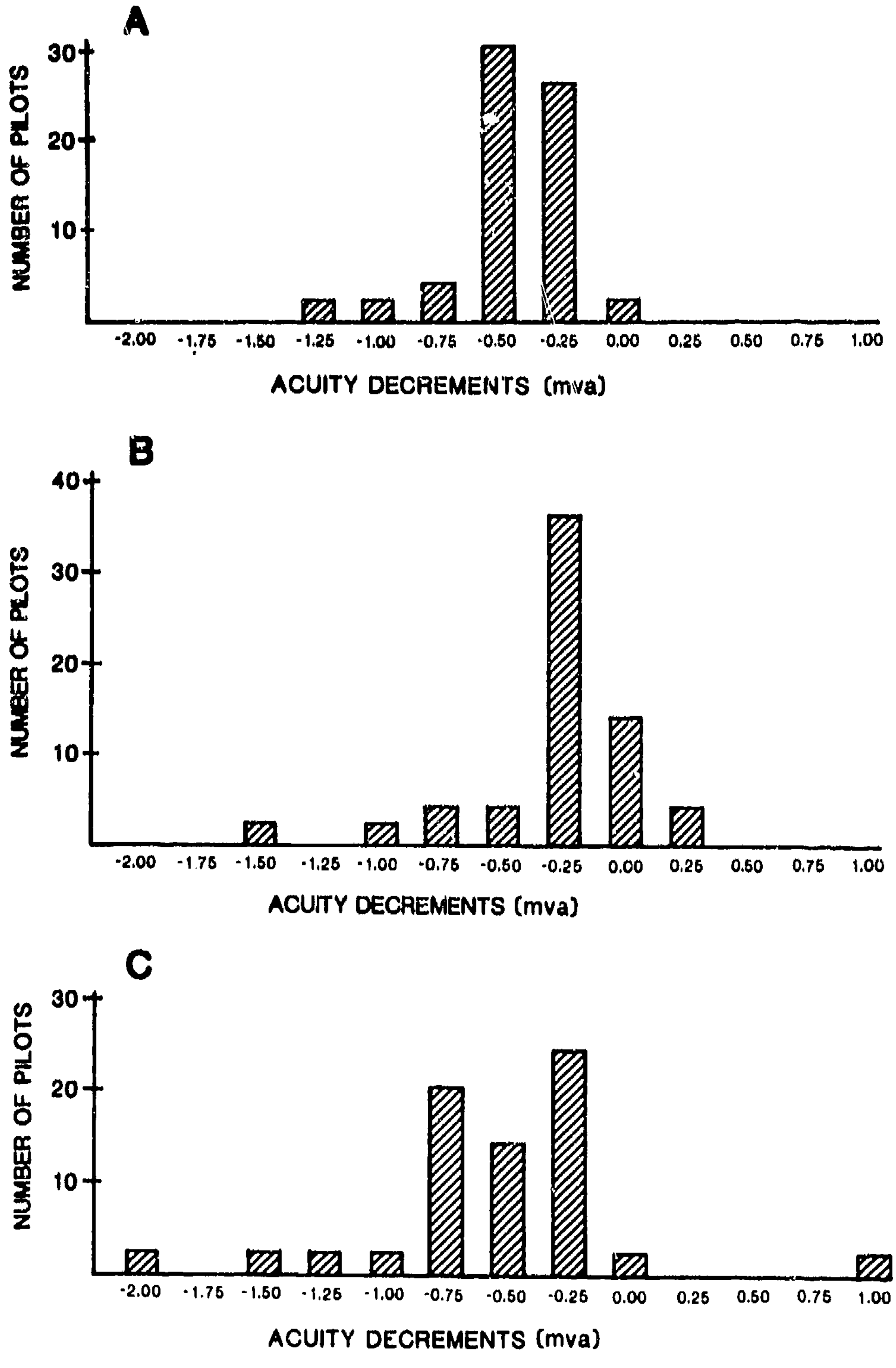

Figure 2. Distributions of decrements in static acuity thresholds due to reduced contrast (A), the presence of glare (B), and the presence of glare and the neutral density visor (C). Midpoints of acuity class intervals are indicated.

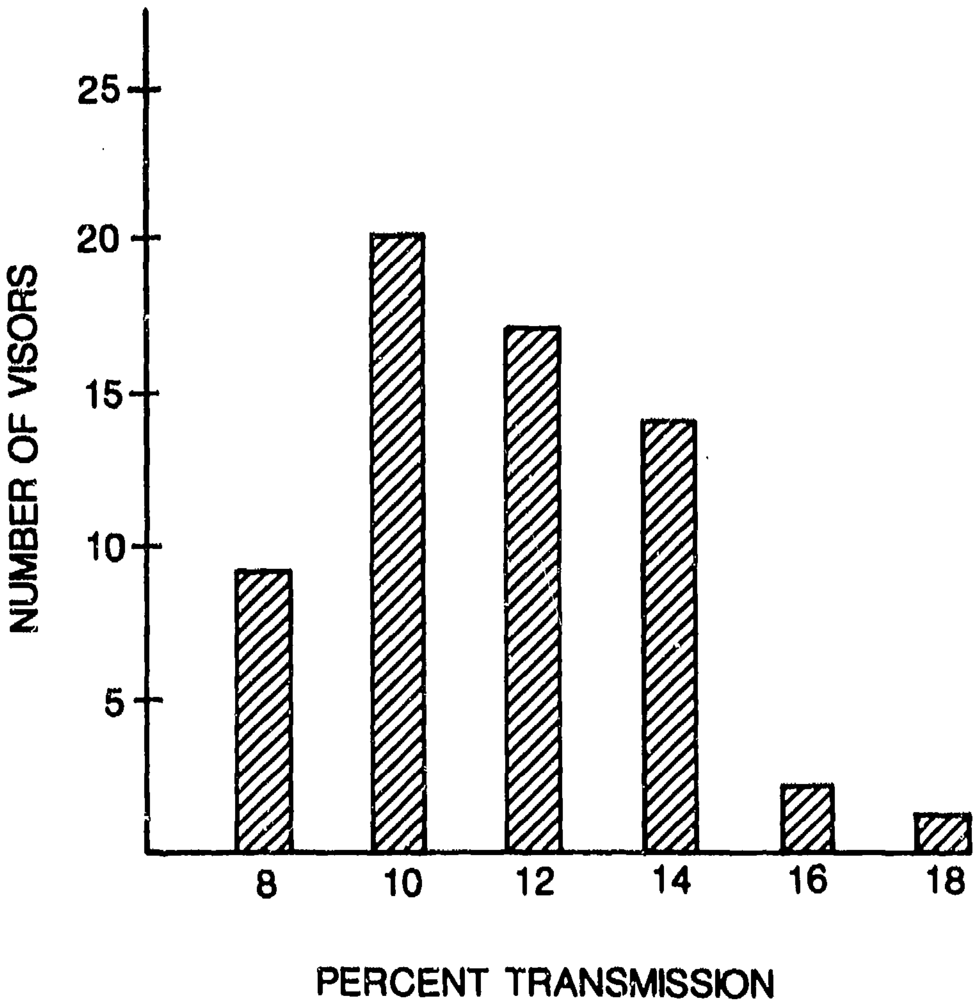

Figure 3. Distribution of percent light transmission for the neutral density visors worn by 63 Navy fighter pilots. Midpoints of transmission class intervals are indicated.

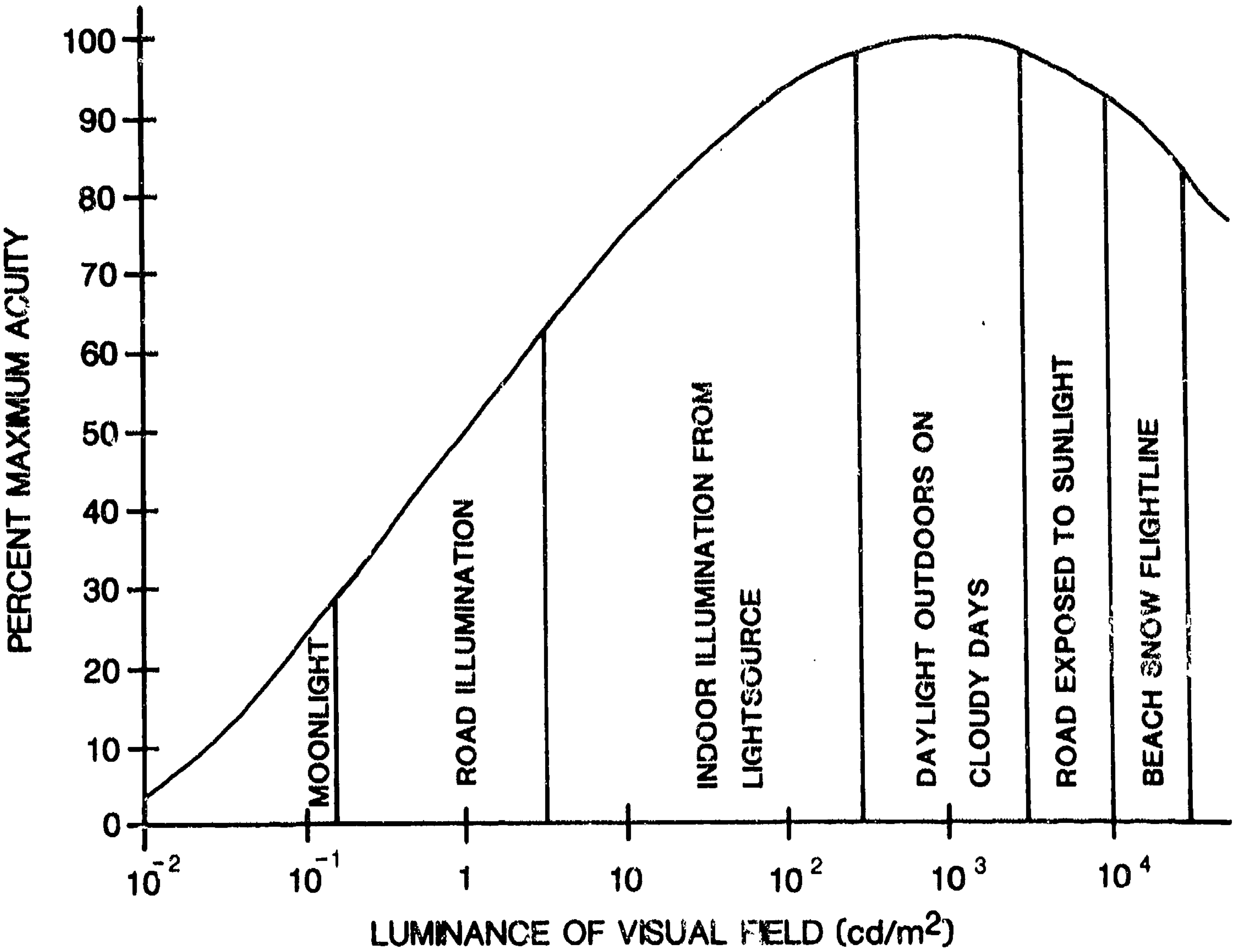

Figure 4. Relationship between high contrast acuity (as percent of maximum) and ambient luminance. (after Daumann, 1982)

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