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PROCEEDINGS OF THE TRI-SERVICE AEROMEDICAL RESEARCH PANEL FALL TECHNICAL MEETING

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Naval Aerospace Medical Research Laboratory
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FALL TECHNICAL MEETING

Vision Research and Aircrew Performance

Proceedings of the
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What the aviator sees during an aircraft carrier landing at night.

This document, titled:

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VISION RESEARCH AND AIRCREW PERFORMANCE

APPENDICES

Keywords: air to air target detection; haze; glare; contrast; night vision goggles; oculomotor nerve; low visibility; space perception; low luminance

VISION RESEARCH

AND

AIRCREW PERFORMANCE

ABSTRACT

The Tri-Service Aeromedical Research Panel (TARP) Fall Technical Meeting was held on 13-14 November 1984 at the Sherman Inn, 224 East Garden Street, Pensacola, Florida.

Invitees were the TARP membership, the TARP member laboratories representatives from the three services' R&D communities, as well as other relevant military and civilian communities. The purpose of the meeting was to provide a forum for information exchange between vision scientists and clinicians from all three services as well as the civilian scientific community. The emphasis of the presentations was on vision research relevant to problems affecting military aircrew performance. This meeting served to ensure close interservice cooperation in vision research, and to assist in identifying future research requirements. Topics included:

-Contrast sensitivity
-Dark focus/night vision
-Ocular motility
-Accommodative flexibility
-Depth perception
-Clinical visual parameters
-Visual screening
-Human factors in aviation
-Dynamic visual acuity
-Visual performance thresholds

The two days were devoted to invited talks and discussions within these topical areas, and concluded with a report from the National Research Council Committee on Vision.

WELCOME TO THE PARTICIPANTS

William M. Houk

Captain, Medical Corps
U. S. Navy
Commanding Officer
Naval Aerospace Medical Research Laboratory

Nineteen hundred and eighty-four marks the tenth anniversary of the commissioning of the Naval Aerospace Medical Research Laboratory as an independent command conducting medical research and development in support of naval aviation. You are cordially invited to join us in the manner in which we wish to celebrate, which is to host scientific and technical information exchange with our colleagues in the Army, Navy, Air Force, NASA, academia, and industry.

The conference, under the charter of the Tri-Service Aeromedical Research Panel, and the sponsorship of the Naval Medical Research and Development Command, is designed to blend the mission-specific vision research of DOD with that of other federal agencies and civilian institutions. The National Research Council Committee on Vision is participating actively and will lend its considerable skill and prestige to our deliberations.

Also, you are invited to explore what makes Pensacola the finest place to live and work in the United States, and to see the way the Navy trains its aviators of the future.

Welcome aboard!

I. VISION TESTING IN OPERATIONAL ENVIRONMENTS

VISUAL FACTORS IN FLYING PERFORMANCE

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SUMMARY

The human visual system has several specific sensitivities including those for visual acuity, color, depth, motion in depth, motion and changing size. Different sensitivities show different intersubject variations. Therefore, if different flying tasks involve different specific sensitivities, the same visual test will not predict performance in all tasks; different tasks will require different tests. A further point is that precise discriminations of clearly-visible targets (e.g., between different trajectories or speeds or sizes) are important in many flying tasks, and discrimination is known to be somewhat dissociated from sensitivity. This line of thought was tested by comparing visual test results on pilots with their flying performance in a simulator and in telemetry-tracked jet aircraft. Tasks included restricted visibility landing, low-level flight, and air-to-air combat. Flying performance correlated more closely with motion discrimination between clearly visible targets than with threshold sensitivity measures including visual acuity, contrast threshold and motion threshold.

Visibility and invisibility: Four ways in which an object can be visually detected

This paper discusses visual tasks in which an observer must respond to the presence and motion of environmental objects. In flying tasks these objects may be other aircraft or terrain features.

Clearly, if he is to respond to an object, the observer must first detect the existence of the relevant object. It is well known that object detection is best if the observer is looking in the right direction and knows what object he is looking for, but even then the object will only be detected if the physical difference between object and background exceeds the threshold of the particular observer's eye. An object's boundaries can be physically defined in several ways including: (a) brightness difference across the boundary (i.e., by luminance contrast); (b) motion difference across the boundary (i.e., by motion contrast, as when a tiger moves across a jungle background); (c) color difference across the boundary (i.e., by color contrast); (d) depth difference between the object and background (i.e., by depth contrast, as when stereo-enhancing binoculars are used to break camouflage). Although discussions of the target detection question are often restricted to objects defined entirely by black-white luminance contrast, any one of the four cues above can, by itself, segregate an object from its background and allow it to be recognized. An important point is that the spatial and temporal summation properties of human vision differ for the different modes of object detection. For example, for objects made visible by motion contrast alone, temporal summation time is 750 msec and spatial summation area 0.16 deg^2 compared with 60 msec and 0.033 deg^2 for objects defined entirely by luminance contrast (1). Again, small objects defined by color contrast alone are less visible than small objects defined by luminance contrast alone, but the reverse is true for large blurred objects (2).

Knowing it is there is not enough

Although an observer must visually detect an environmental object before a visually-guided response is possible, detection is only the beginning of the story. Consider, for example, the would-be tennis player with excellent visual acuity and contrast sensitivity who cannot distinguish between a rapidly moving ball and one moving a little less quickly, or between a service aimed one meter to his left and a service aimed one meter to his right. His problems are ones of discrimination rather than detection. The first is a failure of speed discrimination, and the second a failure to discriminate the direction of motion in depth. Such a player may see the ball clearly and may even be coached to play the correct replay; but when faced with even a moderately skilled opponent, our would-be tennis ace is reduced to uncoordinated impotence.

It is true that early visual detection of a distant object can sometimes be crucial in military aviation; the survival value of seeing one's adversary before he sees you, was already evident at the birth of air-to-air combat over the Western Front in 1914-15, most compellingly so to the occupants of unarmed scout aircraft, and to the artillery observer standing solitary in the basket of a tethered hydrogen-filled balloon. Nevertheless, in their demands on acute discriminations, many flying tasks are not too far removed from the tennis player's problems. In air-to-air combat between armed opponents, there may well be a period when the adversaries can clearly see each other, and the issue is not yet decided; this situation demands of the pilot acute and accurate judgments of distance, speed and trajectory so that the future position of the adversary can be anticipated. These are not detection problems at all, but rather are problems of discrimination. Similar considerations apply in low-level flight, landing, aerial refuelling and formation flight. Therefore, we suggested, intersubject differences in visually-guided flying performance of pilots might be partly due to intersubject differences in the visual ability to discriminate between different velocities, trajectories and so on (3).

Specific sensitivities in human vision

The human visual system has several specific sensitivities. These include specific sensitivities to color, depth, motion, motion in depth, and changing size. It has been proposed that these specific sensitivities reflect the presence of separate functional subunits in the human visual pathway, and that these functional subunits operate approximately independently of each other. Thus, some subjects are blind to color while retaining normal visual acuity, motion sensitivity, depth perception, etc. Again, the visual field of some subjects contains regions that are "blind" to stereo motion in depth while retaining normal sensitivity to position in depth (4). At a less extreme level, normally-sighted subjects show considerable variations in their relative sensitivity to contrast, motion, depth, changing size and color. In the present context of visual factors in aviation, the implication is that the value of one particular threshold (e.g., for grating contrast detection) does not necessarily tell us anything about other thresholds (e.g., those for motion, depth and changing size).

The hypothetical functional subunits that underlie these specific sensitivities have been called "sets of channels" (5). The color system can be taken as a prototypical set of channels. At the earliest level the color system comprises three independently-functioning parallel cone mechanisms whose sensitivities overlap considerably. By analogy with the color system, it has been suggested that the set of spatial frequency channels comprises six channels, the motion in depth set of channels comprises four channels, the depth system comprises two or three channels or "pools", and the changing size set of channels comprises two channels. Although the sets of channels (e.g., color and depth) are supposed to operate substantially independently, this does not always seem to be the case for channels within a given set (reviewed in ref 5).

<u>The physiological basis for acute discriminations between closely similar directions of motion, and between closely similar velocities, orientations, sizes and colors</u>

In color vision it has long been known that, although the three cone mechanisms perform only a crude analysis, analyzing the roughly 250 nm of the visible spectrum into three broad overlapping bands, color discrimination is remarkably acute; a subject with normal color vision can easily discriminate two colors whose wavelengths differ by only 3 nm. According to Hering's theory of color vision, this apparent paradox is explained by supposing that whether or not one sees a light is determined by the most active cone mechanism(s), but color discrimination is determined by the relative activity of the three cone mechanisms. The acuity of discrimination will, therefore, be limited, not by the bandwidths of the three mechanisms, but by their noise levels. In particular, the outputs of the three mechanisms are supposed to drive opponent-color mechanisms that generate difference signals (e.g., a red-green signal), and it is these difference signals that determine color discrimination.

We can once again use color theory as a prototypical explanation, this time for acute discriminations. Subjects can discriminate two directions of stereoscopic motion in depth that differ by only 0.2 deg, yet the most sharply tuned motion-in-depth channel responds to a much broader range of directions of about 2 deg (6,7). The surprisingly acute 0.2 deg directional discrimination can be explained if the relative activity of motion-in-depth channels determine an individual's ability to distinguish different directions of motion in depth (7).

This approach to discrimination can be pursued further. At the first stage of analysis, spatial form information is supposed to pass through multiple parallel subunits, each of which passes a restricted range of spatial frequencies and orientations (8). Each of these subunits or "channels" is tuned to a fairly broad range of spatial frequencies (approximately 1.4 octaves). On the other hand, subjects can distinguish two spatial frequencies that differ by only 2%-5%. In order to explain this disproportionally acute discrimination of size, it has been suggested that spatial frequency discrimination is determined by the relative activity of neurons tuned to different spatial frequencies (9), and in particular that opponent-size mechanisms exist in human vision (10). A finding supporting this idea is that, after adapting to a high-contrast grating of S cycles/deg and S cycles/deg test grating is less visible, but discrimination near S cycles/deg is slightly improved, while discrimination is degraded near 2S cycles/deg where visibility is little affected.

Subjects can discriminate line orientations that differ by only 0.3 deg-0.8 deg. This has been reconciled with the much wider 14 deg-26 deg orientational bandwidths of cortical neurons, by supposing that orientation discrimination is determined by an opponent-orientation mechanism (11,12). Supporting evidence includes the finding that adapting to a high-contrast vertical grating improves orientation discrimination for vertical gratings while at the same time rendering them less visible, and degrades discrimination for gratings inclined at 20 deg to the vertical while not affecting their visibility (12).

Frontal plane motion provides a final example. The visual system contains subunits that respond to a rather broad (about ± 20 deg) range of directions of motion (13). This broad directional tuning can be reconciled with subjects' ability to distinguish between directions of motion differing by only a few degrees if we suppose that directional discrimination is determined by the relative activities of the broadly-tuned subunits (5). Again, cortical neurons are rather broadly tuned to speed, but animal and human subjects are able to distinguish between speeds that differ by only 5% or so. This can be explained if speed discrimination is determined by the relative activities of neurons that may be broadly tuned to speed.

Specific visual tests for specific flying tasks

These channeling ideas have implications for visually-guided flying performance. We have argued that the visual system has a number of specific sensitivities, and that any one sensitivity cannot confidently be predicted from the others. If one flying task involves only one or two of these specific sensitivities, then flying performance in that task will correlate with those one or two sensitivities but not necessarily with other sensitivities. A second flying task that involves different specific sensitivities will correlate with these different sensitivities (5). A similar argument holds for subjects' ability to make discriminations along different dimensions such as speed, direction and orientation. This line of argument leads to the idea that flying performance in different tasks will be better predicted by using different visual tests for different tasks, rather than attempting to predict performance in all flying tasks with a single test measure such as visual acuity or contrast sensitivity (5).

A second point concerns the independent operation of the "sets of filters" discussed above. If the various sets of filters do not operate completely independently of one another, then learned visual performance may degrade in a complex visual environment. For example, a pilot might have high sensitivity to motion in depth, and be capable of accurately holding position in formation flight when there is no appreciable vibration as in some simulators. However, if motion in depth sensitivity is upset by simultaneous frontal plane motion, then the pilot's formation flight performance will deteriorate when the aircraft is subject to vibration in flight.

Laboratory and airborne visual tests used in studies of flying performance

Flying performance was compared with the results of several laboratory tests that were designed to measure specific sensitivities and discriminations that seemed likely to be important in carrying out the designated flying tasks. The tests were as follows. Visual sensitivity to motion in depth was assessed by a motion-in-depth tracking test (3,14). The subjects observed a bright square displayed on a CRT. External circuitry caused the size of the square to change randomly. The subject's task was to maintain the square's size constant by adjusting a lever. The RMS error in the subject's settings was recorded over a 30-sec trial period. In order to assess the independence of the changing-size sensitivity, the motion-in-depth tracking test was repeated while the square was "jittered" in the frontal plane by a noise waveform. Superthreshold motion discrimination was measured using an expanding flow pattern generated on a CRT. The pattern was presented twice, and subjects were required to judge whether the rate of expansion was faster or slower on the second presentation. Several subsidiary measurements were also made including visual acuity, sinewave grating contrast threshold at 5 c/d and contrast threshold for motion detection.

Airborne visual tests were also carried out (15). Two telemetered A-4 aircraft flew towards each other from a range of 25 miles. The pilot of aircraft A was instructed to signal on sighting aircraft B. The pilot of aircraft B was instructed to turn sharply to left or right on hearing the signal, and the pilot of aircraft A signalled the direction of turn of aircraft B. Both visual acquisition distance and the separation of the aircraft at the instant at which turn direction was signalled were recorded.

Comparison of flying performance and visual test results

Two studies compared visual test results with flying performance on the Advanced Simulator for Pilot Training at Williams Air Force Base. Landing performance in restricted visibility and formation flight performance correlated both with tracking test results and with superthreshold velocity discrimination (16,17). Pilots who were better able to discriminate different rates of expansion of the radial flow pattern achieved a greater proportion of hits and misses in a low-level flight and bombing task.

In a third study (15), flying performance was measured in telemetry-tracked high performance jet aircraft (F-14 and A-4) at the U. S. Marine Corps Air Station, Yuma Air Combat Training System Range (TACTS). The two flying tasks were air-to-air combat and low-level bombing. Motion discrimination test results correlated with bombing accuracy, confirming the simulator findings in real flying conditions. The results of airborne visual tests correlated with the win/loss ratio in air-to-air combat, and tracking test results correlated with the number of missiles fired per engagement. Subsidiary tests of thresholds for sinewave grating contrast, motion and visual acuity did not correlate with flying performance either in the simulator or in telemetry-tracked aircraft.

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REFERENCES

1. Regan, D. and Beverley, K.I. 1984. Figure-ground segregation by motion contrast and by luminance contrast. J. Opt. Soc. Am. 1:433-442.

2. Hilz, R. and Cavonius, C.R. 1970. Wavelength discrimination measured with square-wave gratings. J. Opt. Soc. Am. 60:273-277.

3. Regan, D. and Beverley, K.I. 1980. Visual responses to changing size and to sideways motion for different directions of motion in depth: Linearization of visual responses. J. Opt. Soc. Am. 11:1289-1296.

4. Richards, W. and Regan, D. 1973. A stereo field map with implications for disparity processing. Invest. Ophthal. 12:904-909.

5. Regan, D. 1982. Visual information channeling in normal and disordered vision. Psychol. Rev. 89:407-444.

6. Beverley, K.I. and Regan, D. 1973. Evidence for the existence of neural mechanisms selectively sensitive to the direction of movement in space. J. Physiol. 235:17-29.

7. Beverley, K. I. and Regan, D. 1975. The relation between discrimination and sensitivity in the perception of motion in depth. J. Physiol. 249:387-398.

8. Braddick, O., Campbell, F. W. and Atkinson, J. 1978. Channels in vision: Basic aspects. In: Held, R., Leibowitz, H. W. and Teuber, H. L. (Eds.), Handbook of Sensory Physiology (Vol. 8). Springer, New York.

9. Campbell, F. W., Nachmias, J. and Jukes, J. 1970. Spatial frequency discrimination in human vision. J. Opt. Soc. Am. 60:555-559.

10. Regan, D. and Beverley, K.I. 1983. Spatial frequency discrimination and detection: Comparison of postadaptation thresholds. J. Opt. Soc. Am. 73:1684-1690.

11. Westheimer, G., Shimamura, K. and McKee, S. 1976. Interference with line-orientation sensitivity. J. Opt. Soc. Am. 66:332-338.

12. Regan, D. and Beverley, K. I. 1985. Postadaptation orientation discrimination. J. Opt. Soc. Am. 2, in press.

13. Levinson, E. and Sekuler, R. 1980. A two-dimensional analysis of direction-specific adaptation. Vis. Res. 20:103-108.

14. Regan, D. and Beverley, K.I. 1982. Method and apparatus for measuring eye-hand coordination while tracking a changing size image. U.S. Patent 4,325,697. U.S. Air Force.

15. Kruk, R. and Regan, D. 1983. Visual test results compared with flying performance in telemetry-tracked aircraft. Aviat. Space Environ. Med. 54:906-911.

16. Kruk, R., Regan, D., Beverley, K.I. and Longridge, T. 1983. Flying performance on the Advanced Simulator for Pilot Training and laboratory tests of vision. Human Factors 25:457-466.

17. Kruk, R., Regan, D., Beverley, K.I. and Longridge, T. 1981. Correlations between visual test results and flying performance on the Advanced Simulator for Pilot Training (ASPT). Aviat. Space Environ. Med. 52:455-460.

AIR-TO-AIR TARGET DETECTION

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SUMMARY

The purpose of this project was to compare the visual capacities of aircrew to their target detection abilities during air combat maneuver (ACM) training. Preliminary analyses of data for 91 male aircrewmen indicate that high and low contrast acuity, and lateral movement sensitivity, may be used as predictors of target detection ability. Vision data may be combined with key ACM performance data to provide a means of assessing or predicting aircrew target detection performance.

INTRODUCTION

The purpose of this report is to summarize some of the data collected from a vision testing project performed on Navy aircrew members. These data were collected in conjunction with a tasking requirement that specified the need to quantify the visual demands of air-to-air combat and to relate those demands to visual capabilities of the participating aircrews.

To accomplish this tasking requirement, a state-of-the-art automated Vision Test Battery (VTB) was developed and installed in a Mobile Field Laboratory, consisting of two 40-foot trailers. These specially outfitted trailers were transported to the Tactical Air Combat Training System (TACTS) site located at the Naval Air Station, Oceana, VA. Eight squadrons of aircrew members (N = 91) were examined in this Mobile Field Laboratory. Furthermore, flight experience and peer ratings were obtained for all participants, as well as TACTS summaries of flight and engineering data from over 600 air combat training engagements.

This project represents a first attempt at relating a carefully tailored battery of vision tests to a selected aircrew task (target detection) in a specific operational setting (air-to-air combat). Previous investigators have evaluated peer rating as a subjective means of predicting target detection performance (1), and have suggested means of refining TACTS data to provide an objective method of quantifying target detection ability (2,3). However, until the post-Vietnam era, there were insufficient hardware, software, statistics, and resources available to address the combined issues of visual capability and performance criterion development.

Approximately eight years were required to develop the hardware, software, and targets that make up the VTB. Two additional years were required to test the system for functional and psychometric reliability. The efforts of the personnel involved in this project would not have been successful had it not been for the cooperation and support of the Commodore and aircrew of FITWING ONE. Their professionalism and concern are reflected in the volume and quality of data collected.

METHODS

Subjects Ninety-one male aircrew members (pilots) were studied. They ranged in age from 25 to 41 years. These pilots comprised two distinct groups. Group A consisted of 18 members of the adversary squadron stationed at NAS Oceana. The group had accumulated an average of 1888 flying hours, including an average of 639 hours flying ACM. They flew F-5 and A-4 aircraft on most ACM missions. Adversary aircraft are not radar-equipped, so Group A pilots depended solely on vision for target detection. Group B consisted of 73 members of seven operational squadrons, home-based at NAS Oceana, which were participating in the Fleet Fighter Aircrew Readiness Program (FFARP). The group had accumulated an average of 1749 flying hours, including an average of 294 hours flying ACM. They flew F-14 aircraft on all ACM missions, and used both radar and vision to detect targets.

Vision Data Nine vision tests were selected on the basis of their reliability (4) and their relevance to the fleet tasking requirement. These tests were administered to all participating aircrew members. The nine tests yielded a total of 17 vision threshold variables. The tests were:

* Central Acuity (high contrast)
* Central Acuity (low contrast)
* Central Acuity (low contrast) with glare
* Central Spot Detection
* Lateral Movement Detection (left and right)
* Accommodative Flexibility (far to near)
* Dynamic Visual Acuity (2Ø, 5Ø, 11Ø degrees/sec target velocity)
* Contrast Sensitivity (Ø.5, 1.Ø, 3.Ø, 6.Ø, 11.4, 22.8 cycles/deg)
* Dark Focus

Dynamic visual acuity data were obtained for 83 pilots, contrast sensitivity data were obtained for 59 pilots, and dark focus data were obtained for 88 pilots. For all other tests, data were obtained for all 91 pilots. The test designs and data collection procedures are outlined in previous reports (5,6).

Performance Data The FFARP incorporates the use of the Tactical Aircrew Combat Training System (TACTS), a computer-based telemetry system which provides real-time flight information at the first verbal utterance of "TALLYHO." "TALLYHO" is the term used by aircrew to indicate initial target detection. Flight and engineering data were used to obtain the "slant range" for each sortie of each pilot at the instant of the "TALLYHO" call.

Slant range is the actual distance (in nautical miles) separating the observer and target aircraft, inclusive of any altitude differences. The average slant range value for each pilot served as the objective measure of his target detection performance. The amount of the observer's visual field filled by the target at TALLY HO, termed target "angular width", was also computed for each sortie. Angular width incorporates slant range and information about the target aircraft's type and attitude, and both aircraft's altitudes and headings.

In addition, peer rankings were obtained for target detection performance on 67 of the 91 pilots. Raw ranks were transformed to "RANKIT" values, and an average RANKIT score was obtained for each pilot. RANKIT score is a subjective estimate of target detection performance.

Data Analysis: Correlations were computed between each vision variable (N = 17) and both performance measures for both groups A and B. Then, for the slant range performance measure, the 73 Group B pilots were subdivided into pilots above and below the group's mean slant range, and correlations were computed between each vision variable and slant range, for each subgroup. Next, the 73 Group B pilots were subdivided using mean RANKIT score, and the same type of analysis was repeated. Finally, stepwise ($P \leq 0.15$) and forced ("MAXR" in SAS) multiple regressions were conducted for all Group B pilots using all vision variables (except for dynamic visual acuity and contrast sensitivity) as independent variables, and both performance measures as dependent variables.

RESULTS

The slant ranges for Group A pilots ($\bar{X}$ = 6.77; SD = 1.5) and Group B pilots ($\bar{X}$ = 4.74; SD = 1.32) were significantly different (t = 5.7, $P<.0001$). These differences are almost completely due to differences in target aircraft size. Group A was detecting F-14s and Group B was detecting F-5s and A-4s, and F-14s are nearly twice the size of F-5s and A-4s. This explanation is supported by the fact that the angular widths (in minutes of visual angle) for Group A pilots ($\bar{X}$ = 2.40; SD = 0.7) and Group B pilots ($\bar{X}$ = 2.13; SD = 0.9) were not significantly different (t = 1.2, P = .1747).

The threshold data for the vision tests performed on the eight squadrons of pilots are summarized in Table 1. Frequency distributions for the dynamic visual acuity tests showed a distinct positive skew (i.e., a drawn-out tail at the high end of the range of values). Many pilots whose scores were responsible for this skew were 35 or older.

Correlations between vision variables and both of the performance measures are summarized for Groups A and B in Table 2.

Table 1. Descriptive Statistics for Vision Test Thresholds

Vision Test	N	Mean	SD	Range
Central Acuity, High Contrast	91	.40	.07	.27 to .72
Central Acuity, Low Contrast	91	.78	.16	.50 to 1.20
Central Acuity, Low Contrast with Glare	91	1.00	.24	.55 to 1.65
Spot Detection	91	.45	.08	.32 to .63
Lateral Movement, to Right	91	.59	.33	.19 to 2.10
Lateral Movement, to Left	91	.67	.43	.23 to 2.77
Accommodative Flexibility	91	.29	.09	.17 to .86
Dynamic Visual Acuity				
20 deg/sec	83	3.60	2.78	1.48 to 14.96
50 deg/sec	83	7.60	7.43	1.87 to 37.70
110 deg/sec	83	15.82	14.66	2.65 to 94.99
Contrast Sensitivity				
0.5 cycles/deg	59	1.57	.25	1.01 to 2.09
1.0 cycles/deg	59	1.93	.28	1.34 to 2.88
3.0 cycles/deg	59	2.30	.27	1.71 to 2.96
6.0 cycles/deg	59	2.19	.27	1.71 to 3.10
11.4 cylces/deg	59	1.91	.22	1.41 to 2.63
22.8 cycles/deg	59	1.29	.31	.56 to 2.03
Dark Focus	88	-.72	.85	-2.91 to .91

Table 2. Vision variables correlating significantly ($P \leq 0.05$) with two performance measures for Groups A and B.

	Performance Measures	
	Slant Range	RANKIT Score
Group A	None	Spot Detection
Group B	Central Acuity, High Contrast	Accommodative Flexibility
	Contrast Sensitivity (11.4 cycles/deg)	Dynamic Visual (110 deg/sec)

For both measures of target detection performance, above-average pilots would have a higher-than-average slant range score, and a positive (higher-than-average, where average = 0) RANKIT score. Below-average pilots would have the opposite combination of scores. Analysis of subgroups of Group B pilots divided by each performance measure (Table 3) revealed that more vision variables correlated with performance measures for below-average pilots than for above-average pilots.

Table 3. Number of vision variables significantly ($P \leq 0.05$) correlated with two measures of target detection performance for Group B pilots showing "above-average" and "below-average" performances.

Performance Measure Used For Distinguishing Groups	Above-Average Pilots	Below-Average Pilots
Slant Range	4	8
RANKIT Score	1	5

When a stepwise regression analysis was performed on the Group B data (see Table 4), 15% of the variance in mean slant range scores was accounted for by three vision tests (central acuity at high and low contrast, and lateral movement to the left). Forcing the remaining vision variables into the model yielded no appreciable improvement in R-squared value. When a stepwise regression was conducted with RANKIT score as the dependent variable, only one vision variable (accommodative flexibility) entered the model, accounting for 8% of the variance. Forcing the remaining vision variables into the model yielded an R-squared value of .1937.

Table 4. Results of Multiple Regression Analysis for Group B.

Stepwise Regression			Forced (MAXR) Regression (All Independent Variables Entered)
Dependent Variable	Independent Variables Entering	R^2	R^2
Slant Range	Central Acuity, High Contrast Central Acuity, Low Contrast Lateral Movement, to Left	.1525	.1600
RANKIT Score	Accommodative Flexibility	.0829	.1937

DISCUSSION

The data presented here indicate that it may be possible to predict target detection performance from selected vision tests. From 15-19% of the variance in performance score can be accounted for solely by these vision test variables. When vision variables were forced into a regression, they predicted RANKIT score slightly better than they predicted slant range The slightly stronger relationship between vision variables and RANKIT score may indicate the need to identify other factors in ACM that have a strong influence on target detection performance.

The analyses thus far performed do not consider other variables known to influence target detection performance. For example, target angular width is known to account for over 30% of the variance in slant range. Furthermore, target detectability is undoubtedly influenced by target angular velocity, target contrast, sun angle, and other factors. It is essential that further multivariate analyses be employed to identify other TACTS variables significantly influencing target detection performance.

Pilot, flight, engineering, and environmental data have been entered into a file on a mainframe computer. This file includes data from over 600 sorties with over 80 variables. Analyses are being performed on these data in order to define meaningful subsets of TACTS data that can be incorporated with vision data to improve and refine the predictive capability of the vision tests.

In summary, determining which measures of visual capability contribute to target detection performance in ACM is important to the operational community. Inspection of the data indicates that three vision test scores (high and low contrast acuity, and lateral movement to the left) can predict 15% of the variability in slant range at target detection. These data may then be combined with other key TACTS variables to provide squadron COs with useful tools for assessing or predicting the target detection performance of their aircrew. In addition, these tests may provide insight for vision training programs for aircrews, and may influence engineering specifications for future avionics development.

Subsequent reports will outline progress toward refining the TACTS performance measure (slant range), and progress toward adapting the Vision Test Battery for other operational tasking requirements.

REFERENCES

1. Jones, T. N. and R. E. Doll. 1974. Peer ranking as a criterion measure for initial acquisition of targets. NAMRL Avia. Psych. Tech. Memo. 74-2.

2. Hutchins, C. W. and T. N. Jones. 1975. An initial investigation of those ACMR parameters related to initial air-to-air visual acquisition. NAMRL Aero. Psych. Dept. Tech. Memo. 75-2.

3. Hutchins, C. W., Jr. 1978. The relationship between air combat maneuvering range (ACMR) output measures and initial visual acquisition performance. NAMRL Special Report 79-1.

4. Monaco, W. A., A. Morris, and P. V. Hamilton. In preparation. Visual requirements for air-to-air target detection. NAMRL Report.

5. Morris, A. and J. Goodson. 1983. The development of a Precision series of Landolt ring acuity slides. NAMRL Report 1303.

6. Molina, E. A. 1983. Digital system controller to administer tests of the vision test battery. Preprints ASMA, pp.42-43.

CONTRAST SENSITIVITY: RELATING VISUAL CAPABILITY TO PERFORMANCE

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SUMMARY

This report summarizes a seven year program conducted by the AFAMRL Aviation Vision Lab that demonstrates an approach to create new performance related vision standards. Certain limitations of present methods of visual assessment using acuity are shown to be overcome using a more complete vision test: contrast sensitivity an automated contrast sensitivity test is compared to other test candidates in terms of stability, reliability and repeatability. An optimum test resulting from the previous criteria was used to collect large civilian and Air Force pilot contrast sensitivity data. Individual differences in pilots' contrast sensitivity are shown to predict simulated air-to-ground target detection and actual ground-to-air target detection. Finally, recommendations are given for the creation of vision standards based upon this research program.

Standard Vision Testing - Existing visual standards for pilots are based on their ability to see high contrast black and white letters or symbols on an eye chart. Although visual acuity is a good measure of the optical focusing characteristics of the eye, it is primarily a measure of visual quantity, not quality. Unfortunately, visual acuity has not related well to visual performance in conditions requiring detection of targets of different size and contrast. Current eye charts with only one high level of black and white contrast are not sensitive to how we see different size targets of different contrasts. The auditory equivalent to a high contrast eye chart would be a hearing test with only one high level of loudness for all sound frequencies tested, hardly a sensitive hearing test. Obviously good optical quality is desired, but a more sensitive vision test is needed to test the total visual system including the retina/brain system.

Contrast Sensitivity Testing - The retina/brain system converts the retinal image into a visual code based primarily on the shape and contrast of the target. Since targets come in a wide range of different size, shape and contrast, sensitivity of the visual system should be tested with a set of simple targets that can represent any target size, shape, and contrast: sine wave gratings (Fig. 1).

A sine wave grating is a repeated sequence of light and dark bars whose luminance profile varies sinusoidally about a mean luminance with distance. The width of one light and one dark bar of a grating is one cycle, or the period of the grating. The reciprocal of the period is the spatial frequency. Spatial frequency is the number of cycles of the grating that occur over a particular distance. The spatial frequency of an object can be expressed by cycles per object dimension or more commonly, by cycles per degree of visual angle (cpd). The luminance difference of modulation of the light and dark bars determines the contrast of the grating. In a typical measurement for contrast sensitivity, the contrast of the sine wave grating, usually generated on a TV display, is increased until the bars are just at the threshold of visibility and the subject reports detection. Measurements are repeated for a number of bar widths (spatial frequencies). The reciprocal of contrast threshold is plotted as a function of spatial frequency to create a contrast sensitivity function (CSF) (Fig. 2).

Instead of using sine wave gratings to test vision, why not use letters, sharp discs or fuzzy circles of different sizes and contrast, patterns that look more like targets? Simply, the sine wave grating is a mathematically special target, and any complex target can be duplicated from a combination of gratings, and measuring the visual contrast sensitivity to these gratings can give a measure of the visual sensitivity to more complex targets, especially when used in conjunction with appropriate models of vision. The lower sensitivity of disks and letters as compared to gratings due to how the visual system processes those targets have been shown (Fig. 1). Just as hearing tests use sound intensity and single sound frequencies to measure auditory sensitivity to complex sounds, contrast sensitivity tests use contrast and single spatial frequencies to measure visual sensitivity to complex targets. Using contrast sensitivity allows a linear systems approach to provide a quantitative analysis for specifying relevant target information, visual filter characteristics, and visual capability and performance within a single framework having "throughput" (2).

Although contrast sensitivity provides a more complete and sensitive measure of spatial vision than acuity measurements, its ability to relate to visual performance, such as target acquisition, had to be shown. In general, 20/20 vision means that a certain visual sensitivity exists from only about 18 to 30 cpd (2). If our visual system had only one filter that made up the contrast sensitivity function, then perhaps a single acuity value such as 20/20 would adequately describe the contrast sensitivity function. Instead, there are many smaller filters, receptive fields grouped together called channels, that comprise the contrast sensitivity function (Fig. 2). Since these channels are almost independent from one another, high sensitivity for one size channel does not mean high sensitivity for all other channels. Therefore, 20/20 acuity over 18 to 30 cpd cannot necessarily describe the sensitivity of channels below 18 cpd or above 30 cpd. This is why some people can pass an eye chart test, but do not see well under low contrast viewing conditions. Decreased sensitivity to low and middle spatial frequencies can occur in certain individuals.

Pilots' Vision Testing - Since visual standards for pilots are based on visual acuity, which is not sensitive to lower or middle spatial frequencies, there may be significant individual differences in these frequency ranges even for pilots with similar acuity. This means that the visual capability of pilots to see targets with larger size and lower contrast than the last line read on their eye charts is unknown.

Three Air Force pilots at AFAMRL had their contrast sensitivity measured in early 1979 (2,3). The surprising results are shown in Figure 3. Although pilot B had a lower visual acuity than the other two pilots, his contrast sensitivity below 4 cpd is significantly higher than that of pilot C. The next step was to determine if these differences in contrast sensitivity between pilots was typical and to determine how important the differences might be.

To determine the variability of contrast sensitivity for vision, large population contrast sensitivity measurements were needed. A quick, repeatable, sensitive, and cheat-proof test for a computer controlled video display was developed (4). This test measures a contrast sensitivity function in about 12 minutes, or about the time needed for a hearing test. That test, used in 1980 to test 285 observers at the Dayton Air Fair and the Air Force Museum, produced a large population data (5). Since then, over 1000 individuals have been tested, including over 100 Air Force pilots and 80 Air Force Academy cadets. The contrast sensitivity differed by an average factor of over 3 over the range of spatial frequencies tested (1 to 24 cpd). About 10 to 15% of the population have good acuity but low contrast sensitivity for low and middle spatial frequencies (similar to pilot C, Fig. 3).

Contrast Sensitivity and Visual Performance - Next, differences in contrast sensitivity were related to differences in visual performance. Contrast sensitivity differences have been shown to be predictive of the visibility of stationary targets for the detection and identification of letters and aircraft silhouettes in the laboratory (2). In an air-to-ground detection study, differences in contrast sensitivity resulted in differences in detection range (6). During simulated landings, 11 Air Force instructor pilots were required to press a button on detecting a MIG aircraft at the end of the runway. Standard acuity and contrast sensitivity were compared to detection range. The results (Fig. 4) show that contrast sensitivity, not visual acuity, predicts the pilots' detection range. For example, two pilots had similar acuity under normal light conditions, but had peak contrast sensitivities that differed by factors of 1.4 and 2.2 under normal and low light conditions. Although both pilots used the same detection criterion, the pilot with the higher contrast sensitivity detected the MIG at a distance 2.4 times greater than his colleague. This difference translated into detection time differences of 21 seconds for clear and 10 seconds for fog visibility conditions between these most and least sensitive pilots.

Similar results have been found in recent field studies (7). Eighty-four Air Force pilots reported detection of approaching T-39 aircraft for ten field trials in visibility conditions ranging from one-half mile to over 15 miles. The visual capability was measured using the standard acuity and contrast sensitivity tests and correlated to detection range. Contrast sensitivity correlated significantly to detection range for 8 of 10 field trials. Visual acuity correlated in 3 of 10 field trials, one trial with a significant negative correlation. The average difference in detection range and time between the most and least sensitive pilots for all visibility conditions was 2.2 miles and 56 seconds. These differences in target acquisition capability are important for the success of visually demanding military ground, air, and space missions.

These results also have important implications for safety in other visually demanding tasks such as driving automobiles and trucks. The increased detection time needed to detect a target due to low contrast sensitivity also produces poor visual performance for detection of other vehicles, pedestrians, road hazards, and signs. One study compared the capability of young and old adults to discriminate between two road signs in a simulated driving task found that, even though both age groups had similar visual acuity, the older group had lower contrast sensitivity. The younger group was able to discriminate the road signs at a distance 24% greater than the older group.

Contrast Sensitivity and Displays - This contrast sensitivity approach is not just limited to quantifying visual capability, but extends to quantifying display/simulator systems as well. Contrast sensitivity has been used to relate the contrast losses of three different candidate heads-up displays (HUD) for the F-16 (8,9). Although these HUDs had passed specifications, pilot complaints about one of the HUDs required an evaluation related to mission performance. The solution was to measure pilots' contrast sensitivity both around and through the HUDs. The difference between the two contrast sensitivities provided the contrast loss, due to the HUD optical characteristics, that was directly related to the pilots' ability to see targets. The contrast loss was then related to differences in detection range attributed to contrast sensitivity found from the field trial data discussed earlier to determine performance loss penalties. This contrast sensitivity approach suggests unifying standards for both observers and display systems.

These results are not meant to imply that the contrast sensitivity test equipment or test methods presented here are the best for all test situations. Different test equipment and methods will be useful depending upon user needs. Constraints of quick screening for large populations, to more stringent requirements for job selection, to the highest criteria to detect subtle visual diseases will require equipment and methodology concomitant to those needs. Such factors as cost, test time, ease of useability and analysis, as well as the scientific constraints of criterion effect, stability, sensitivity, and reliability will require careful consideration. For example, a new contrast sensitivity test chart has recently been tested (10). This chart uses photographs of gratings with different spatial frequencies and contrast, similar to Fig. 1. In less than five minutes, this new chart can be used to obtain a contrast sensitivity function that compares quite closely to that obtained using a computer-based video system and is currently being used to measure visual changes of astronauts in space.

Creating Performance Related Vision Standards - The creation of a loss penalty due to decreased contrast sensitivity of the HUDs points toward one way to begin creating performance related vision standards using contrast sensitivity. Decreased contrast sensitivity has been shown to relate to decreased target detection range. The importance of that loss on operational performance will depend upon the particular mission. Obviously, high contrast sensitivity, hence good visual capability, is of prime importance to the combat pilot, perhaps less important for the transport pilot. This means that vision standards, in addition to relating to clinical standards, will have to relate to operational requirements as well. These results suggest that differences in contrast sensitivity less than a factor of about 2 will generally not provide major differences in visual capability. Initial analysis should concentrate on those individuals having contrast sensitivity greater than about ±0.33 from the average population. The performance of those individuals should be tracked and tested along with their peers to determine the extent that contrast sensitivity impacts on mission capabilities.

REFERENCES

1. Ginsburg, A. P. Sine wave gratings are more visually sensitive than disks or letters. J. Opt. Soc. Am. A1:1301, 1984.

2. Ginsburg, A. P. Spatial filtering and vision: Implications for normal and abnormal vision. In: Proenza, L., J. Enoch, and A. Jampolsky (Eds.). Clinical Applications of Psychophysics, Cambridge University Press, New York, 1981.

3. Ginsburg, A. P. Proposed new vision standards for the 1980s and beyond: contrast sensitivity. Proc. AGARD No. 1310 (AFAMRL-TR-80-121), 1981.

4. Ginsburg, A. P., and M. W. Cannon. Comparisons of three methods for rapid determination of threshold contrast sensitivity. Invest. Ophthalmol. Vis. Science 24:798-802, 1983.

5. Ginsburg, A. P., Evans, D. W., and Cannon, M. Large sample norms for contrast sensitivity. Am. J. Optom. Physiol. Opt. 61:80-84, 1984.

6. Ginsburg, A. P., D. W. Evans, R. Sekuler, and S. A. Harp. Contrast sensitivity predicts pilots' performance in aircraft simulation. Am. J. Opt. & Physiol. Opt. 59:105-109, 1982.

7. Ginsburg, A. P., J. Easterly, and D. W. Evans. Contrast sensitivity predicts target detection field performance of pilots. Proc. Human Factors Soc., 269-273, 1983.

8. Ginsburg, A. P. Specifying relevant spatial information for image evaluation and display design: an explanation of how we see certain objects. Proc. SID 21:219-227, 1980.

9. Ginsburg, A. P. Direct performance assessment of HUD display systems using contrast sensitivity, Proc. NAECON, 33-44, May 1983.

10. Ginsburg, A. P. A new contrast sensitivity vision test chart. Am. J. Opt. & Physiol. Opt. 61:403-407, 1984.

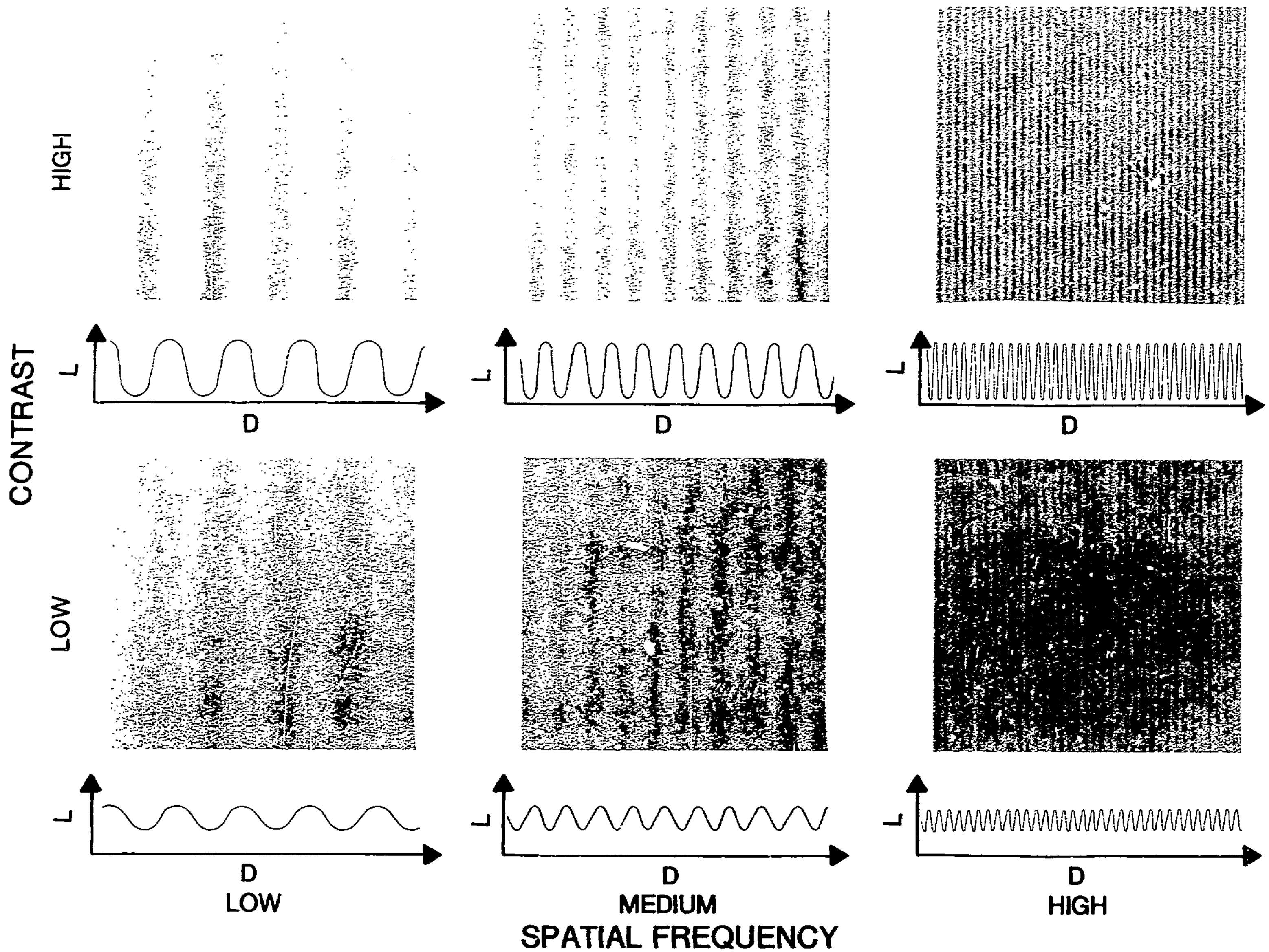


Figure 1.

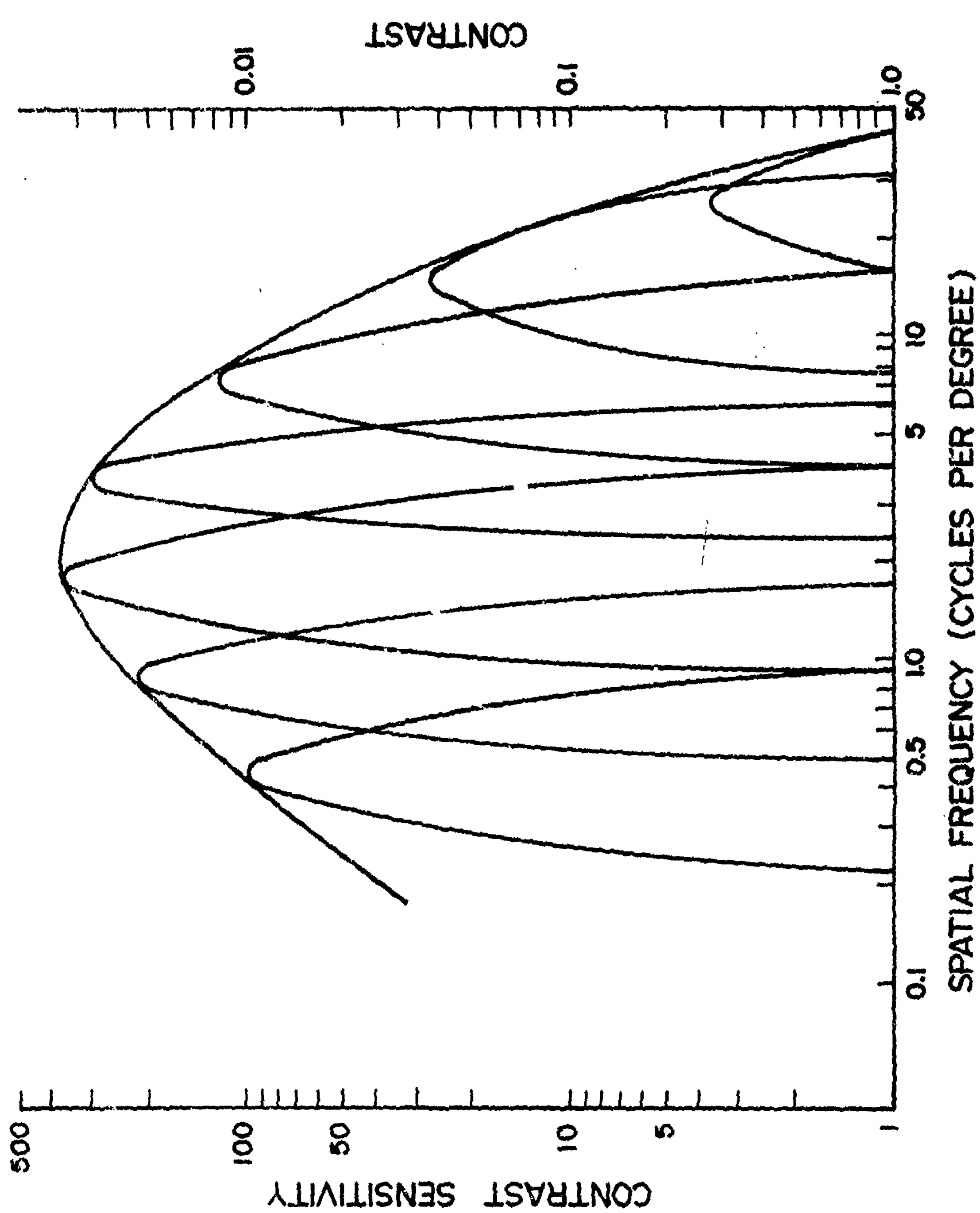
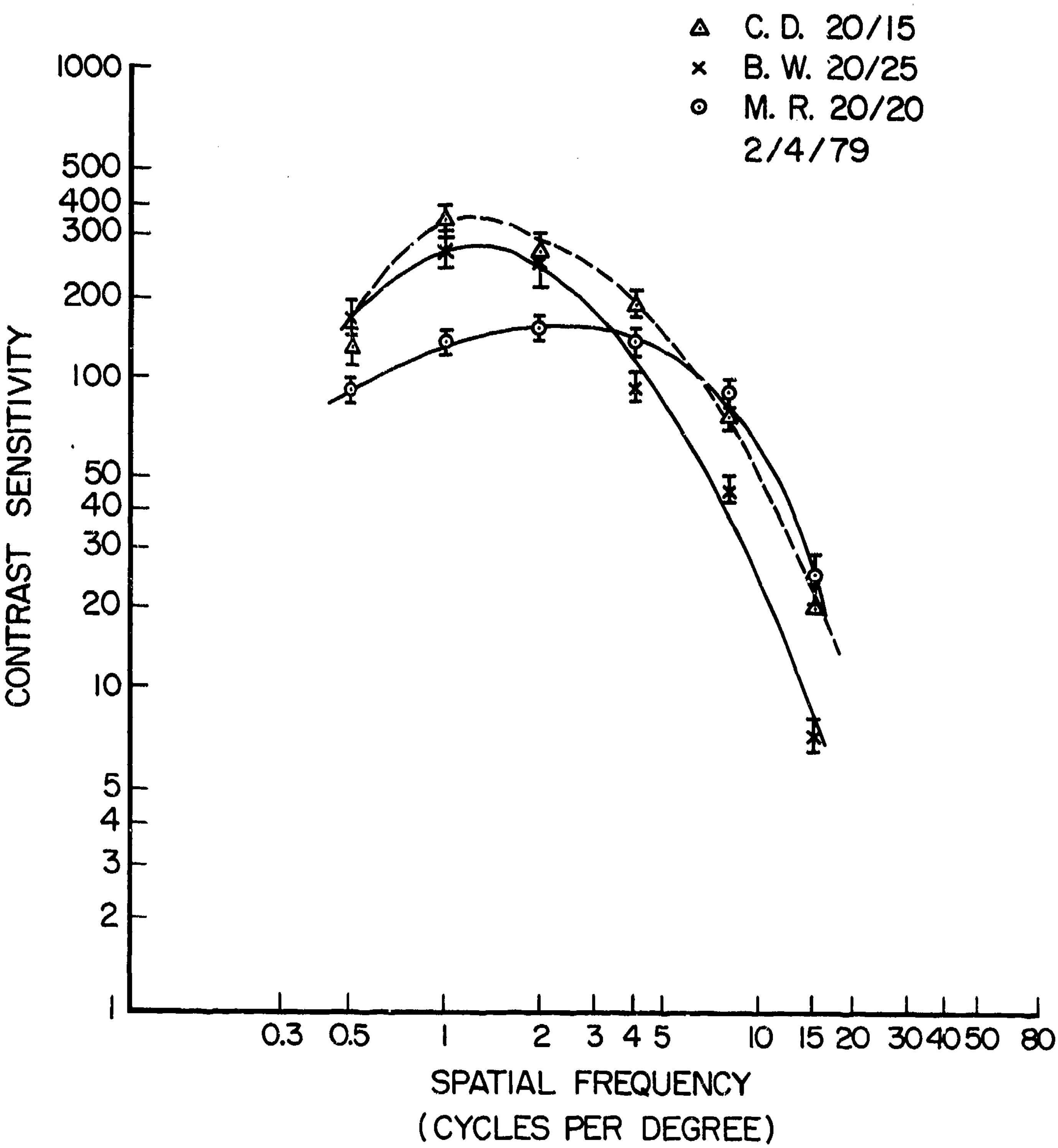

CONTRAST
0.01
0.1
1.0
CONTRAST SENSITIVITY
500
100
50
10
5
1
SPATIAL FREQUENCY (CYCLES PER DEGREE)
0.1
0.5
1.0
5
10
50

Figure 2.


C. D. 20/15
B. W. 20/25
M. R. 20/20
2/4/79
CONTRAST SENSITIVITY
1000
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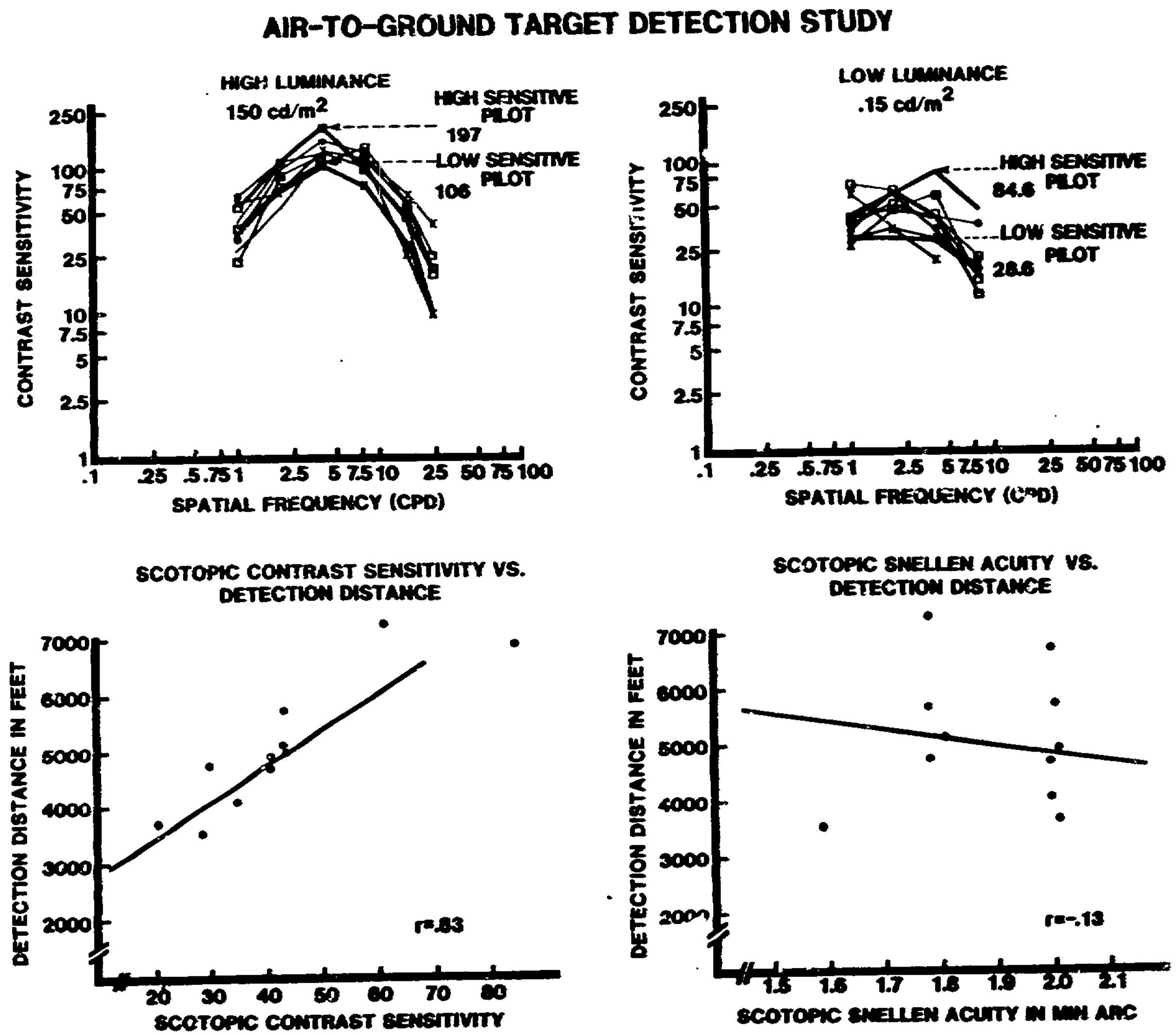
SPATIAL FREQUENCY
(CYCLES PER DEGREE)

Figure 3.



AIR-TO-GROUND TARGET DETECTION STUDY
HIGH LUMINANCE
150 cd/m2
HIGH SENSITIVE PILOT
197
LOW SENSITIVE PILOT
106
CONTRAST SENSITIVITY
SPATIAL FREQUENCY (CPD)
LOW LUMINANCE
.15 cd/m2
HIGH SENSITIVE PILOT
84.6
LOW SENSITIVE PILOT
28.6
SCOTOPIC CONTRAST SENSITIVITY VS. DETECTION DISTANCE
DETECTION DISTANCE IN FEET
r=.83
SCOTOPIC CONTRAST SENSITIVITY
SCOTOPIC SNELLEN ACUITY VS. DETECTION DISTANCE
r=-.13
SCOTOPIC SNELLEN ACUITY IN MIN ARC

Figure 4.

FACTORS AFFECTING DYNAMIC RESOLUTION

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SUMMARY

The present study explored the possibility that factors in addition to retinal image motion are involved in determining dynamic resolution. In experiment I, retinal image motion during pursuit enhanced contrast sensitivity for a 1 cy/deg frequency and degraded sensitivity for a 4 and 12 cy/deg grating when oriented vertically. When the gratings were viewed horizontally, in the direction of pursuit, dynamic sensitivity was less than static sensitivity regardless of spatial frequency. In experiment II, choice response time recorded during pursuit increased as much as 70 msec while error rates increased by 10% over stationary performance levels. The results suggest that dynamic resolution should be considered a dual task. Dynamic resolution is a function for the subject's static performance, retinal image motion, and the effort required to pursue the display.

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INTRODUCTION

For many visual tasks there is either motion of the observer, the object, or some combination of both. Without the ability to dynamically resolve detail (dynamic visual acuity - DVA) we would not be able to read a sign while walking or driving a car. Pilots would have difficulty determining whether an object was a plane or just a speck on their windscreen. In short, without dynamic resolution we would be severely limited in our every day lives.

The importance of DVA was recognized as early as 1938 (1). Later studies demonstrated that static acuity was not predictive of dynamic acuity and subjects with the same static thresholds could differ markedly in their dynamic thresholds (2,3,4). The decline in dynamic acuity was believed to result primarily from retinal image motion caused by the inaccuracies of pursuit (5,6,7). However, the few studies which used gratings instead of optotypes as targets revealed some interesting contradictions (8,9,10). In particular, resolution of a grating whose contours were oriented in the same direction as pursuit was degraded (8,9). In another study, contrast sensitivity continued to improve long after pursuit eye movements had ceased to improve (10). Furthermore, a non-resolution task which required the subject to react to the appearance of a target within the pursued spot was also degraded during pursuit (11).

These studies suggest that some factor in addition to retinal image motion is also involved in DVA. Most studies of DVA have used optotypes which makes interpretations difficult. The use of sinusoidal gratings has three distinct advantages over optotypes: (1) gratings allow large stimulus areas to be used which eliminates the contribution of parafoveal viewing as a factor, (2) since retinal image motion has been shown to shift maximum sensitivity along the spatial frequency scale, the use of gratings of different spatial frequencies permits the assessment of retinal image motion, and (3) by changing the orientation of the grating so that the contours are aligned with the direction of pursuit, image motion can be eliminated as a contributing variable.

Experiment I: Dynamic Contrast Sensitivity

Experiment I assesses contrast thresholds for sinusoidal gratings of three spatial frequencies oriented either vertically or horizontally during pursuit. For the vertical orientation, image motion caused by imperfect pursuit should enhance sensitivity for the low while degrading the high spatial frequencies. However, for the horizontal orientation contrast thresholds should not be affected by imperfect pursuit since image motion would not degrade contrast. If contrast thresholds for both orientations are elevated, then a factor in addition to retinal image motion is involved in determining resolution.

METHODS

Subjects. Four emmetropes, one male and three females 21-29 years of age, served as subjects. All were naive in regard to the hypotheses, and had no previous experience with dynamic tracking tasks. They were paid the minimum hourly wage.

Apparatus. The sinusoidal gratings were generated on the face of a 608 Tektronix monitor (mean luminance of 2.4 cd/m^2). Two ten-turn potentiometers connected to the Z axis allowed either the subject or experimenter to vary grating contrast (defined as Lmax-Lmin/Lmax+Lmin).

The monitor was mounted on a platform/arm assembly which moved sinusoidally through a 15.4 deg arc at a distance of 75 cm from the subject. A mask with a seven min of arc fixation point centered in a 3 by 7.5 deg aperture was attached to the front of the platform. A 43.5 by 180 deg of arc matt white background (4.6 cd/m^2 mean luminance) and platform covered the monitor, arm, and pivot point. The modulated signal from a single turn linear potentiometer attached to the arm and pivot point was recorded on an XY plotter to assess target/arm position.

An infrared Gulf & Western eye-trac model 200 was used to assess eye position. The sensors were mounted on the head/chin rest assembly, and provided a resolution of approximately 10 min of arc. The second channel of the XY plotter recorded movements of the left eye.

Procedure. All subjects participated in four experimental sessions. During the first 1.5 hr session, the eye movement monitor was adjusted and calibrated, and the subject's tasks were explained. After this, using the method of adjustment, the subject practiced setting thresholds for the three sinusoidal gratings (1, 4, and 12 cy/deg). Subjects were instructed to use a just-visible criterion.

The three remaining 2-hr sessions were devoted to data collection. The subject was exposed to a single temporal frequency per session (.23, .46, or .91 Hz; the average velocities in deg/sec are 3.5, 7.0, and 14.0). The subject set six thresholds (3 ascending, 3 descending) for both orientations of each spatial frequency for each temporal frequency. Six stationary thresholds were recorded for each spatial frequency. After every threshold the total available Z axis modulation was varied to control for response biases. Subjects were given a break after every six thresholds. Temporal frequency, spatial frequency, and grating orientation were counterbalanced among subjects.

Movements of the left eye were recorded for three out of every six thresholds set by the subject. The eye movement monitor was rezeroed and calibrated after every break.

RESULTS

Fig. 1 illustrates the average gain of pursuit as a function of temporal frequency for the two orientations of the gratings. The average gain did not differ as a function of grating orientation ($F(1,3) = .24$, $p = .20$), however, there was a significant reduction in gain as temporal frequency increased ($F(2.6) = 7.59$, $p = .02$). All interactions failed to reach significance ($p = .10$).

The ratios of stationary to moving contrast thresholds for both orientations for the three temporal frequencies as a function of spatial frequency are shown in Fig. 2. A three factor analysis of variance revealed a significant main effect of spatial frequency ($F(2,6) = 22.55$, $p = 001$), while the main effect of temporal frequency and orientation failed to reach significance ($p = .20$). There was, however, a significant interaction between orientation and spatial frequency ($f(2,6) = 8.34$, $p = .05$) which indicates that the two orientations of the spatial frequencies were differentially affected by image motion.

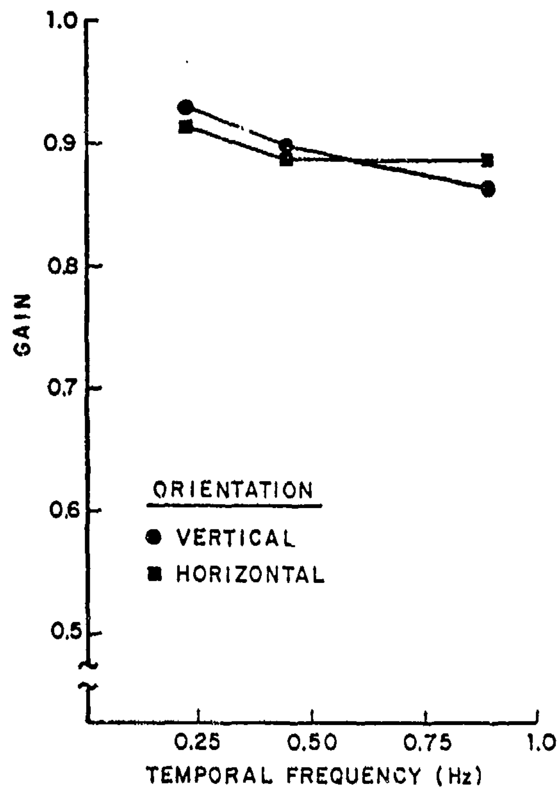

Figure 1. Average gain as a function of temporal frequency for both orientations of the grating.

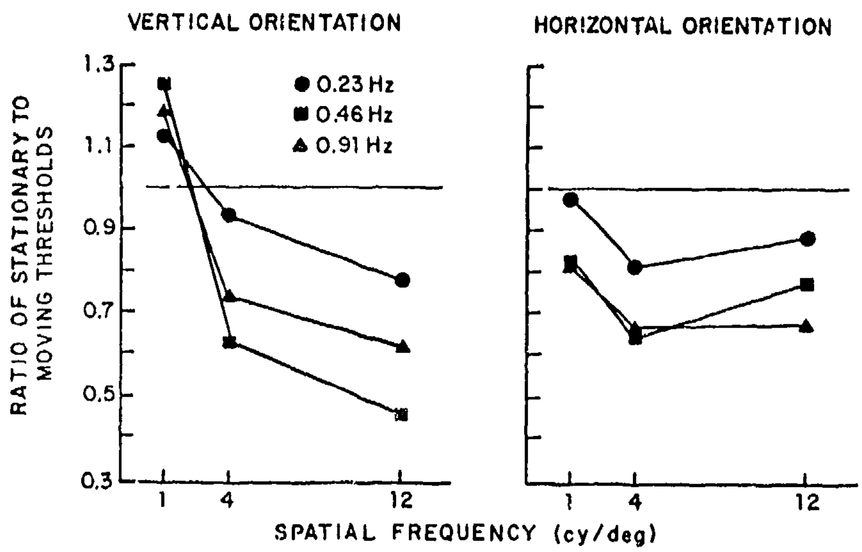

Figure 2. The ratio of stationary to moving contrast thresholds as a function of spatial frequency for the three temporal frequencies.

A two factor analysis of variance was performed for the two orientations of the grating separately. For the vertical orientation, the analysis revealed a significant main effect of spatial frequency ($F(2,6) = 23.05$, $p<.001$) and temporal frequency ($F(2,6) = 6.10$, $p<.03$), while for the horizontal orientation the main effect of spatial frequency and temporal frequency was not significant ($p>.20$). However, the ratios for the horizontally oriented gratings (collapsed over temporal frequency) were significantly less than 1 ($t(2) = 4.07$, $p<.05$).

For the vertical orientation, as predicted by previous studies, contrast sensitivity was enhanced for the low and degraded for the two higher spatial frequencies. The horizontal orientation, however, shows a general reduction in sensitivity for all spatial frequencies. This overall reduction in sensitivity is interpreted as reflecting a cost due to the effort required to maintain pursuit. If the cost is due to an attentional capacity limit, then it should be possible to demonstrate this cost with a response measure which is independent of resolution.

Experiment II: Dynamic Response Time

Experiment II employs three choice reaction time tasks in order to determine if the cost during pursuit is due to an attentional capacity limit imposed by the pursuit system. The tasks were a two choice left-right task with compatible response mapping, a luminance increment/decrement task of a single red light emitting diode (LED), and a luminance increment/decrement of a 3 by 7.5 deg area of the 608 monitor. The monitor task insures that changes in response time are related to off-axis viewing (14).

METHOD

The subjects and the basic apparatus were the same as in experiment I with the following exceptions.

Apparatus. An Apple IIe computer was used to present the stimuli and record the reaction times. The arm rest which previously held the subject's potentiometer was modified to hold a two key response pad. The mean luminance level of the monitor in the increment/decrement task was 2.30 cd/m^2, which either stepped to 3.25 cd/m^2 (increment) or to 1.35 cd/m^2 (decrement). The monitor was replaced with a two LED display centered in the aperature along the horizontal meridian for the two choice and increment/decrement LED tasks. The LEDs were separated by 1 deg of visual arc. The mean luminance level for the LEDs was .86 cd/m^2. Mean incremental luminance was 1.72 cd/m^2, and the mean luminance for the decrement was .48 cd/m^2.

Procedure. The second experiment consisted of three one-hr sessions. The subject was informed which task they would perform during the session and received 100 stationary practice trials.

Subjects performed a total of 60 stationary trials and 40 trials per temporal frequency. Trials were grouped in blocks of 20 with a short rest period between blocks.

Median response times were used in the analyses. Response times associated with errors and any response time less than 100 or greater than a 1000 msec were discarded. Average gain was based on 15 randomly selected pursuit samples for each temporal frequency for each task. Temporal frequency, task type, and response mapping for the increment/decrement tasks were counterbalanced among subjects.

RESULTS

The average gain for the three tasks as a function of temporal frequency is shown in Fig. 3. A two factor analysis of variance demonstrated that gain did not differ among the tasks ($F(2,6) = 0.59$, $p>.20$), however, gain did decrease with increasing temporal frequency ($F(2,6) = 5.00$, $p<.05$) as was observed in experiment I. The interaction failed to reach significance ($p>.20$).

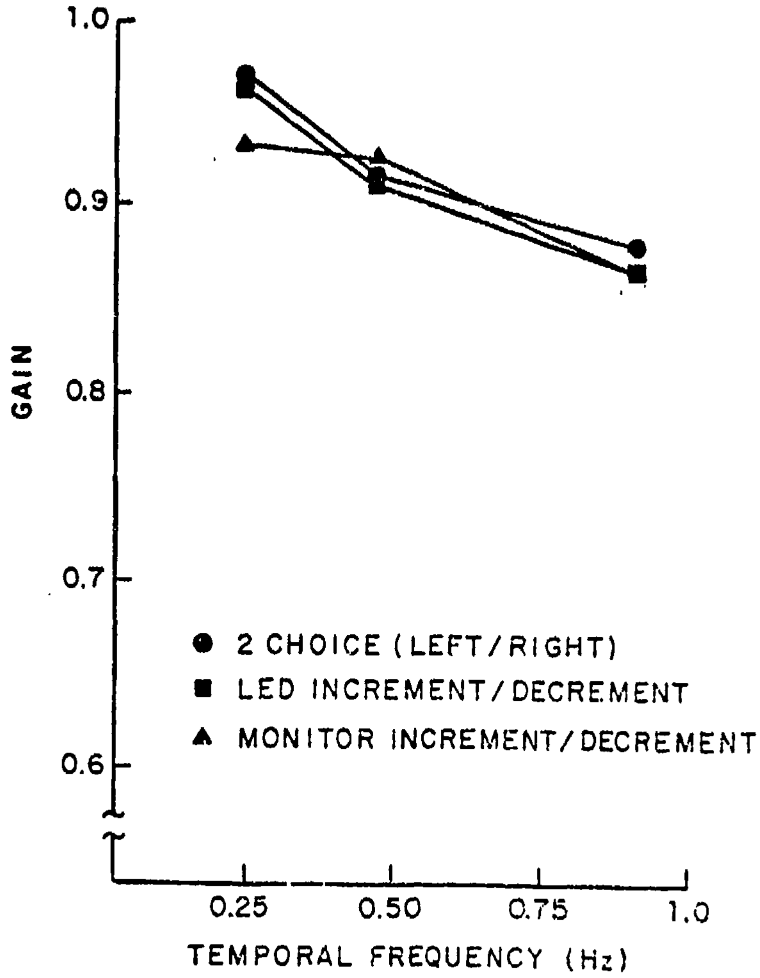

Figure 3. Average gain as a function of temporal frequency for the three choice response tasks.

Fig. 4 illustrates the relationship between response time and temporal frequency for the three tasks. A two factor analysis of variance revealed a significant increase in response time as a function of task type (F(3,9) = 12.19, p= .ØØØ1), and temporal frequency (F(3,9) = 11.ØØ, p= .ØØ2). The interaction reached significance (F(6,18) = 2.6Ø, p= .Ø5) which indicates that the three tasks were differentially affected by temporal frequency.

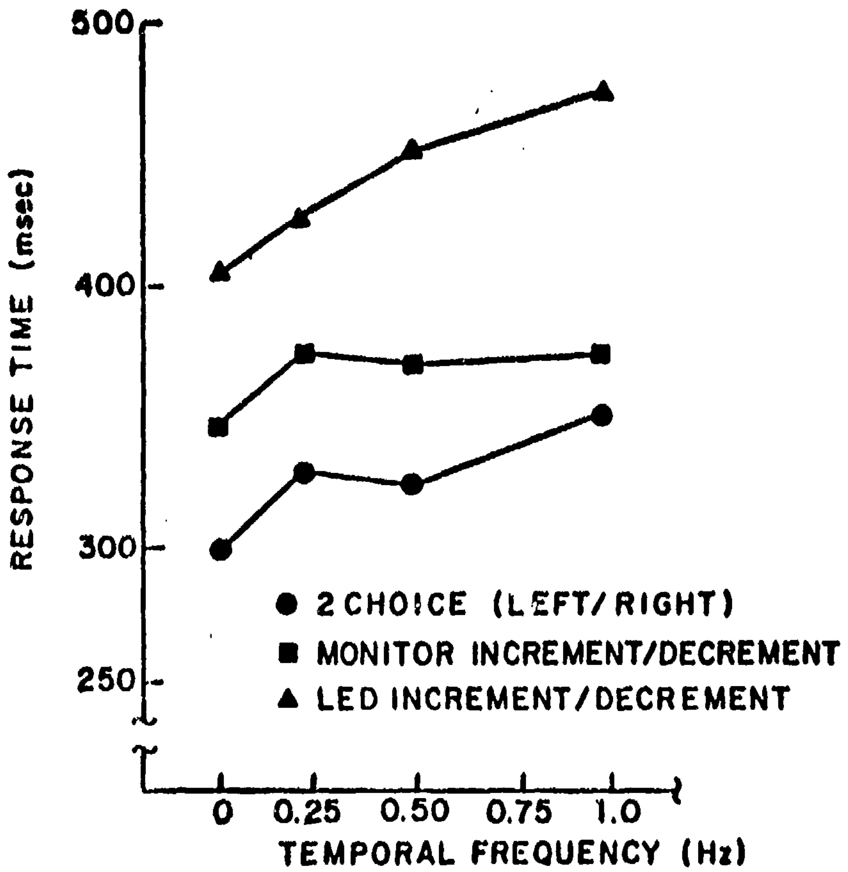

Figure 4. Mean response time as a function of temporal frequency for the three choice response tasks.

Error rates for the three tasks as a function of temporal frequency are presented in Fig. 5. A two factor analysis of variance revealed a significant increase in error rate as a function of task type ($F(2,6) = 6.90$, $p = .02$) and temporal frequency ($F(3,9) = 3.55$, $p = .06$). The interaction, however, failed to reach significance ($p = .20$).

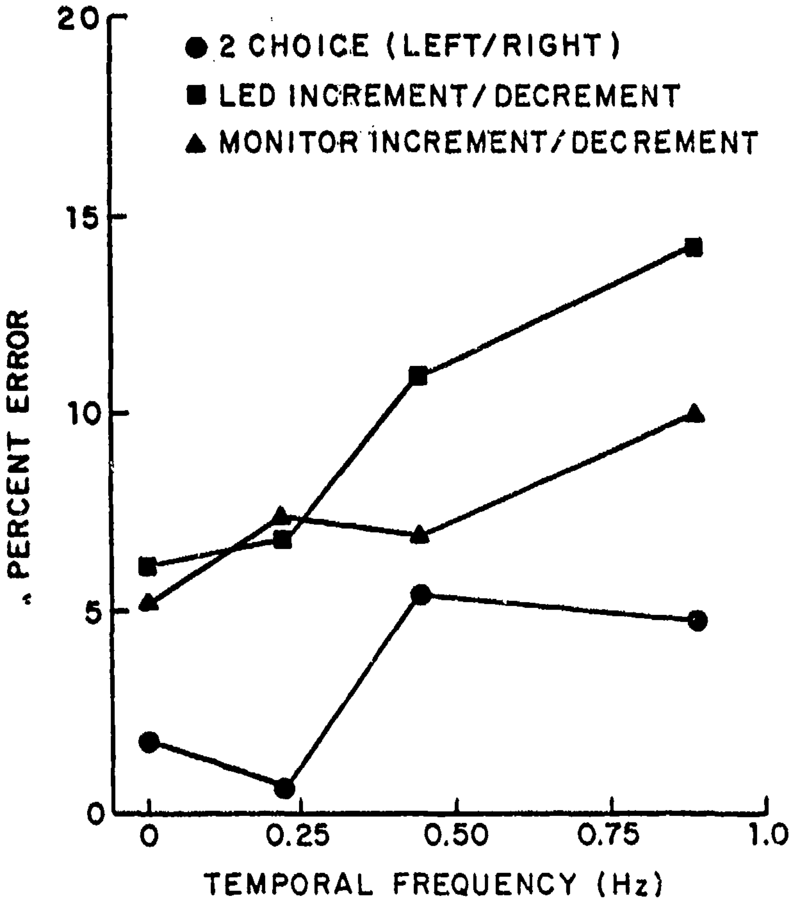

Figure 5. Mean percent error as a function of temporal frequency for the three response tasks.

Experiment II demonstrates a cost associated with pursuit for tasks which place minimal demands on resolution. The increase in response times is not due to off-axis viewing, at least for the monitor task. Therefore, it may be concluded that the cost for these tasks results from the effort of maintaining pursuit.

DISCUSSION

The data from the present experiments demonstrates in accordance with other studies that contrast sensitivity can either be enhanced or degraded by image motion depending on spatial frequency. In addition to the effect of retinal image motion, the data demonstrates that an additional factor is involved in dynamic resolution. The results from the choice response tasks demonstrates an attentional capacity limit independent of resolution which is imposed by the pursuit even for a well practiced, predictable target motion. Dynamic resolution should, therefore, be considered a dual task with both components demanding part of the total capacity. As pursuit demands increase less capacity will be available for the secondary task, whether it be resolving a target or reacting to the appearance of a target.

The present experiments utilize predictable repetitive target motion which lessens the pursuit demands normally encountered outside of the laboratory. It is likely that as target velocity increases and target motion becomes less predictable, or as uncertainty increases the observed effects would exacerbate.

REFERENCES

1. Lagmuir, I. 1938. The speed of the deer fly. Science 87:233-234.

2. Ludvigh, E. J. 1947. Visibility of the deer fly in flight. Science 105:176-177.

3. Ludvigh, E. J. 1948. The visibility of moving objects. Science 108:63-64.

4. Ludvigh, E. J. 1949. Visual acuity while one is viewing a moving object. Arch. Ophthalmol. 42:14-22.

5. Ludvigh, E. J. and Miller, J. W. 1958. Study of visual acuity during the ocular pursuit of moving test objects: I. Introduction. J. Opt. Soc. Am. 48:799-802.

6. Brown, B. 1972. Dynamic visual acuity, eye movements and peripheral acuity for moving targets. Vision Res. 12:305-321.

7. Brown, B. 1972. The effect of target contrast variation on dynamic visual acuity. Vision Res. 12:1213-1224.

8. Mackworth, N. H. and Kaplan, I. T. 1962. Visual acuity when eyes are pursuing moving targets. Science 136:387-388.

9. Barmack, N. H. 1970. Dynamic visual acuity as an index of eye movement control. Vision Res. 10:1377-1391.

10. Murphy, B. J. 1978. Pattern thresholds for moving and stationary gratings during smooth eye movements. Vision Res. 18:521-530.

11. Wertheim, A. H. 1980. Information processing mechanisms involved in ocular pursuit. In: G. E. Stelmach and J. Requin (Eds.), Tutorials in Motor Behavior. North-Holland Publishing Company.

12. Arend, L. E. 1976. Temporal determinants of the form of the spatial contrast threshold MTF. Vision Res. 16:1035-1042.

13. Kelly, D. H. 1979. Motion and vision. II Stablized spatio-temporal threshold surface. J. Opt. Soc. Am 69:1340-1349.

14. Rains, J. D. 1963. Signal luminance and position effects in human reaction time. Vision Res. 3:239-251.

THE YING AND YANG OF VISION IN AIR COMBAT

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LCDR Heatley's briefing included more than 100 color slides which cannot be reproduced here. He used them to illustrate the history of aircraft camouflage and its parallels in the animal kingdom. The members of the TARP were also presented with some of the unique problems encountered when camouflaging aircraft, as well as a look at how paint schemes work. For further information please see the Fall 1980 issue of the TOPGUN Journal, or call LCDR Heatley at VF 124 operations: Autovon 959-3381.

"Lose sight - lose the fight"; an axiom in fighter aviation which has been written in blood. Gaining the first tally (visual contact) and maintaining it has always been the most important ingredient for success in aerial combat. The leading German ace in World War II flamed virtually all of his 352 victims before they even knew he was there. Over Korea, Vietnam, Egypt and Syria, this lesson remained paramount.

Today, the Fighter Weapons School instructors preach it, it is in all the tactics manuals, and the veterans know it to be true; YOU MUST MAINTAIN SIGHT OF THE BOGIE!

If it is so critical to keep sight of the enemy, why isn't it just as critical to make the enemy lose sight of us? Scientists are working on new aircraft designs and special coatings which reduce the radar return. Efforts with paint and shielding to reduce the infrared signature are also underway. What is lacking is the same effort in the visual/electro-optic arena. Perhaps fooling the MK1, Mod 0 eyeball with a camouflage paint scheme is not high-tech enough to receive the proper emphasis.

Ironically, it is the new technology that will bring air combat tactics full circle again, back to the visual engagement. Airborne radars and missiles which operate and kill far beyond visual range can be jammed, cluttered with chaff, or deceived by electronic countermeasures. In fact, operators may choose to leave the radars off so as not to provide a target for enemy anti-radiation missiles or signal an alert on his radar-warning receiver.

In this scenario, our 40 million dollar fighter is now dependent upon a couple of pairs of eyeballs to find the bogies. Would formal vision training help these men? Can knowledge of dark focus, contrast sensitivity, scanning techniques, dynamic resolution, accommodation and oculomotor performance make a difference in air combat?

Meanwhile, those bogie drivers are looking for us! The only protection we have against visual detection by the enemy is a few gallons of paint. Is the paint we wear on our aircraft the most effective camouflage available today? Camouflage has always been considered an art rather than a science. Hopefully, some of the people in this room can attack this problem from a physiological standpoint; what the eye cannot see.

We know that vision has a profound effect on the survivability and lethality of our fighter pilots. Let's enhance ours and degrade theirs.

THE EFFECTS OF HAZE AND GLARE ON VISUAL CONTRAST SENSITIVITY - PRELIMINARY RESULTS

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SUMMARY

In order to provide an estimate of visual degradation produced by slightly turbid transparencies (e.g., windshield, visor, or protective mask) placed before the eyes, the visual contrast sensitivity function (CSF) was determined in five observers with vision unobstructed and with transparencies in place having nominal haze values of 0.5 to 20%. The CSFs were obtained both with an off-axis glare source and without. The forward light scattering produced by hazy transparencies can impair vision by reducing luminous transmittance, by reducing resolution, and, particularly in the presence of an off-axis glare source, by reducing target contrast. In the absence of glare, transparency haze effects were slight and involved only the highest spatial frequencies. The glare source itself reduced contrast sensitivity (except for 0.5 cpd; resulting from intraocular light scattering) and further reduction with the transparencies in place could be well accounted for by the veiling luminance which they produce.

INTRODUCTION

In principle, the optical quality of transparencies needed to support the high visual requirement of military aviation is assured by military specifications and standards (1,2); however, according to Grether (3), "In actual practice, the standards which exist are rather arbitrary, and are based to a considerable extent on what the industrial production technology can provide" (p. 19). Evidence for this assertion is afforded by the wide range of acceptable haze levels, from 0.5 to 6%, found in various specifications (4).

Very little research has been conducted to determine the visual penalty of viewing through hazy transparencies as a basis for establishing standards and specifications. Glover (5), using the Luckiesh-Moss Low-Contrast test chart, measured visual contrast threshold values for unobstructed vision and viewing through transparency samples having various haze values. No data were presented in his report nor was the criterion used to establish permissible limits. His recommendations were: highly desirable, 0.5%; acceptable if other factors take precedence, 1%; maximum value, 2%. The recommendations of more recent workers are considerably less stringent. Shannon (6), on theoretical grounds, recommended a maximum allowable haze value of 10% since an object contrast of .25 would be reduced to a still detectable contrast of .02 to .05 under various illumination conditions. Kay (7) assessed pilot opinion about transparency haze while viewing external scenes through small acrylic samples that had varying levels of haze produced by surface abrasion. The aviators rated each sample using a 9-point scale in which 1 was "Good: Unaware of glass scratches" to 9 "Unsatisfactory: I would not take off with a windshield this bad." Kay found that 80% of the pilots would accept haze levels of 15 to 20% before recommending replacement. Kama, et al. (8) measured the visual field and high contrast target detection thresholds in the presence of glare, viewing through transparencies having a wide range of haze levels. Their data provide a visual performance basis for a cost-benefit analysis of transparency replacement.

In the present study, the visual contrast sensitivity function (CSF) for sinusoidal gratings served as the task for assessing the visual performance loss associated with glare and transparency haze. Contrast sensitivity is the historical method for assessing the effects of glare (9) is currently under consideration for assessing glare sensitivity in relation to driver licensing (10,11), and has become the standard clinical tool for evaluating visual effects of light scattering by the ocular media (12-19). The light scattering produced by hazy transparencies can impair vision in three ways: (a) by reducing luminous transmittance, (b) by reducing resolution, and (c) by reducing target contrast (20). The contrast reducing "noise" produced by scattered light is amplified markedly by an off-axis (glare) source which together with a turbid transparency produce a uniform veiling luminance. To assess this effect, the CSF was determined for a wide range of transparency haze levels in conjunction with a glare source, as well as alone.

METHODS

Subjects: Five observers, 4M and 1F, average age 36.2 years, having 20/20 or better visual acuity binocularly (with correction as needed) and no abnormalities of transparency of the ocular media, were used.

Apparatus: Testing was conducted in a room in which all surfaces, walls, ceiling and floor, were matte black. Room illumination was provided by four recessed ceiling incandescent lamps adjusted to provide 12fc at the observer's table. The contrast sensitivity functions were obtained with a Nicolet Optronics CS2000 Contrast Sensitivity Testing System. The video display had a mean luminance of 26.45 fL, and at the 3-meter viewing distance, subtended 4.39° by 5.57°. This display was surrounded by a high intensity (4300 fL) fluorescent lamp (Aristo DA-17) which was masked so that no direct light reached the screen. Because of the video dimensions, this glare source was closer to the screen on top (4.5 cm) than on the sides (8 cm) or bottom (12.2 cm). The choice of a surrounding glare source instead of a more commonly used laterally placed small glare source was based on the findings of Miller, et al (21). that the former was less fatiguing and helped the subjects maintain fixation on the centrally located target. Fig. 1 shows the general test layout. The mean luminance of the display surround, in the absence of glare, was 3.27 X 10^{-2} fL for the narrow video border, 2.38 X 10^{-1} fL for the glare light housing, and 5.16 X 10^{-2} fL for the background wall.

The hazy transparencies, manufactured by the Rohm and Haas Co., were 24" by 24" by .125" Plexiglas G cast acrylic sheets. Haze measurements were made using the ASTM D1003-6 standard method and were 0.41, 1.05, 2.77, 4.05, 10.1, and 19.34%. The transparencies were positioned for testing such that the eye level distance was .46 m and the top was inclined 9° towards the observer in order to eliminate visible reflections of the glare source from the observer's glasses. The luminous transmittance of the panels was measured with a Spectra Pritchard Photometer, Model 1980A-PL, located at the observer's position with the video display (with no grating) as the source. These measurements are graphically presented in Fig. 2(A). The initial drop of 7.8% is the transmittance loss, primarily due to reflection and absorption, characteristic of .125" acrylic panels while further loss (to about 70% transmittance for the 19.34% haze panel) is linear with increasing haze. However, when the glare source was on, screen luminance measurements instead increased linearly with increasing haze; the difference between the two conditions providing an estimate of the veiling luminance (L_V) produced by the turbid screens in the presence of an off-axis light source. In addition, the video display was set for a 0.5 cpd sinusoidal grating of about 15% contrast and the maximum and minimum luminances were measured with each of the transparencies, from which target contrast was calculated using the formula,

$$C = \frac{L_{Max} - L_{Min}}{L_{Max} + L_{Min}} . \qquad (1)$$

As can be seen in Fig. 2(B), the obtained contrast values remained essentially unchanged for all levels of transparency haze in the absence of the glare source. Under this condition, the transparencies behaved like neutral density filters, which would not be expected to affect target contrast since

$$C = \frac{TxL_{Max} - TxL_{Min}}{TxL_{Max} + TxL_{Min}} = \frac{\tau\,(L_{Max} - L_{Min})}{\tau\,(L_{Max} + L_{Min})} . \qquad (2)$$

When, however, a uniform luminance (L_V) is added to the screen luminances, contrast (C_G) is reduced according to the formula,

$$C_G = \frac{(L_{Max} + L_v) - (L_{Min} + L_v)}{L_{Max} + L_v + L_{Min} + L_v} = \frac{L_{Max} - L_{Min}}{L_{Max} + L_{Min} + 2L_v} = \frac{C}{1 + \frac{2L_v}{L_{Max} + L_{Min}}} \qquad (3)$$

Procedure: The contrast threshold was measured using a variation of the method of increasing contrast (22); first, no preview exposure was given, and second, instead of presenting all trials at a given spatial frequency in a block, an intermixed series of trials was given such that any selected spatial frequency could occur on a given trial with the constraint that each spatial frequency appeared once in each block of six trials. The purposes for these modifications were to distribute transient subjective changes (e.g., criterion change, practice, and fatigue) more uniformly over the spatial frequencies, and by maximizing spatial frequency uncertainty to encourage the observer to adopt a more stable conservative criterion (23). Five estimates of the contrast threshold were obtained for each spatial frequency: 0.5, 1, 2, 4, 8, and 16 cpd, for a given glare and transparency condition. Two conditions, randomly determined differently for each observer, were given in a daily test session. Five warm-up trials preceded actual data collection for any condition. After all conditions were given once (over seven test days), the entire procedure was replicated, and the two sets of five threshold estimates for each observer for each combination of glare and haze conditions were pooled. Because of occasional outliers (perhaps anticipatory responses or lapses of attention), the median log contrast threshold was determined instead of the more usual geometric mean (24).

RESULTS AND DISCUSSION

Effects of Glare on the CSF: Contrast sensitivity functions were obtained in the absence of transparency haze to obtain baseline levels both with and without the glare source. These CSFs, shown in Fig. 3, were evaluated using a two-way repeated measures analysis of variance. The interaction of glare by spatial frequency is highly significant ($F_{5/20} = 4.78$, $p=0.0049$), as is the spatial frequency main effect ($F_{5/20} = 77.99$, $p<.0001$), while the glare main effect was not significant ($F_{1/4}<1$). The glare source reduced contrast sensitivity for all frequencies examined except 0.5 cpd, where a sizable improvement in sensitivity occurred for every observer. The ratio of threshold contrast with glare to threshold contrast without glare is shown in Fig. 4 where it can be seen that the maximum glare effect occurred for the intermediate spatial frequencies (2, 4, and 8 cpd). Two previous studies (15,25) have examined the effects of glare on the CSF, but neither study reported data for spatial frequencies below 1.7 cpd. The 0.5 cpd improvement with glare cannot be explained by pupillary dynamics (mean 5.2 mm without glare, 3.4 mm with glare) since the more optimal pupil size with glare would be expected to affect the higher spatial frequencies (26).

Cohen, et al. (27) found that the surround luminance was a major determiner of the CSF, particularly for the lower spatial frequencies. The low frequency sensitivity was maximum when the luminance of a 12° circular surround was equal to the mean luminance of the display. Sensitivity was reduced both for lower and higher luminance surrounds. Similar results were obtained by McCann and Hall (28), and in one of their studies they compared the effects relative to a dark surround of flanking luminous fields either laterally positioned (along the direction of the sinusoid) or perpendicular to it. Lateral flanks significantly improved the low spatial frequency sensitivity, while vertical flanks had no effect. To determine whether the improvement at 0.5 cpd in the present study related to the improvement found in these studies, the fluorescent glare lamp was partially masked so that it was visible either to the right and left of the display or above and below it. Compared to the sensitivity with the dark surround (20.8), sensitivity with lateral fluorescent light was improved (26.3), with vertical unchanged (21.0).

Thus, because of the operation of a number of factors, the magnitude of the effects of a glare source will vary for different spatial frequency regions.

Effects of Transparency Haze on the CSF: The contrast sensitivity functions obtained with each of the transparencies is portrayed in Fig. 5. The ratio of threshold contrast with the transparencies to that without for each spatial frequency is given in Fig. 6. There is no systematic overall reduction in the CSF with increasing transparency haze ($F_{6/24}<1$), but the interaction of haze level by spatial frequency is marginally significant ($F_{30/120} = 1.85$, $p=.01$; Huynh-Feldt $p=.03$; Greenhouse-Geisser $p=.19$), and reflects the reduction in sensitivity for the two highest spatial frequencies with the two highest haze levels.

Since CSFs show a greater reduction at higher than lower spatial frequencies with decreased average display luminance (29,30) and with blurring (12) the slight result in the present study may be related to both the transmittance and resolution loss with transparency haze. Measurement with a higher spatial frequency target, perhaps 24 cpd, would be expected to show greater haze impairment.

Effects of Transparency Haze and Glare on the CSF: In comparison to the CSFs obtained without the glare source, the CSFs obtained with glare declined across all spatial frequencies proportionately with increasing haze. The main effect of haze was highly significant $F_{6/24}$ = 5.36, p<.01), while the interaction of haze by spatial frequency was not significant ($F_{30/120}$<1). The ratio of threshold contrast with transparency haze and glare to that with glare only is depicted in Fig. 7 and can be seen to increase approximately linearly from 2.77% haze to the maximum level. Returning to Fig. 4, we see that the maximum haze and glare effect occurred for the intermediate spatial frequencies.

The contrast sensitivities obtained with haze and glare are replotted in Fig. 8 as a function of the level of transparency haze. Also shown in this figure are predicted sensitivities based on the increase in target contrast that would be necessary to offset the veiling luminance (L_V), that was produced by each combination of glare and haze. Although an estimate of L_V was provided by the luminance measures given in Figure 2, for this purpose the method of Clark (4) was used. The essential difference was that the video display was replaced by a light trap. The predicted threshold contrast was calculated from the relationship

$$C_p = C \times \left(1 + \frac{2L^V}{L_{Max} + L_{Min}}\right) \quad (4)$$

where C_p is the predicted contrast, C is the contrast at threshold with glare but without haze. It can be seen that correcting for the target contrast reduction produced by the veiling luminance provides very good agreement with the obtained values. Small systematic differences exist between predicted and obtained values for 0.5 and 4 cpd, but whether these are real differences is unknown.

<u>General Discussion</u>: For the conditions of the present study, it was possible to demonstrate a systematic reduction in the contrast sensitivity function for haze values of 2.77% and greater. The ability to measure losses with lower haze levels may be improved with the use of more reliable methods for measuring contrast sensitivity such as a criterion free forced-choice method (14). As an alternative, since the loss in contrast sensitivity was found to be proportional to the ratio of the veiling luminance to the average target luminance, larger effects would have been seen if the average screen luminance had been lower, or if the glare illuminance had been higher.

In order to estimate the real world effects of transparency haze, L_V was determined using the Clark method outdoors on the afternoon of 31 Oct 84. The sun elevation was approximately 19^o to 16^o above the horizon. A 1980-A photometer measured the luminance of the light trap opening with each of the transparencies in turn. A black drape minimized photometer stray light and back reflection from the transparencies. The obtained values appear in Table I.

TABLE 1

VEILING LUMINANCE FOR TRANSPARENCIES OF VARYING HAZE

%Haze	Sky Illuminance, fc	L_V, fL	C_G (Target Contrast=.25)	Factor
19.34	4640	2020.18	.032	7.8
10.10	4750	1188.42	.050	5.0
4.05	4630	452.30	.100	2.5
2.77	4490	306.28	.124	2.0
1.05	4490	98.5	.188	1.3
0.41	4360	78.60	.198	1.3

In comparison with the glare source used to obtain the laboratory data, in which the illuminance at the eye was only 12 fcs and the maximum L_V was 9 fL, on this sunny afternoon values of L_V in excess of 2000 fL were obtained. The apparent contrast, C_G, of a .25 contrast target of 300 fL average luminance viewed through each of the transparencies was calculated and also appears in Table I. The value of C_G=.05 for the 10.1% haze screen is in agreement with the value that Shannon (6) had predicted and represents a factor of five reduction of apparent contrast. While the .25 target may still be visible, it would, indeed, be close to threshold if it was a high or low spatial frequency. Furthermore, targets of somewhat lower contrast, regardless of spatial frequency, would be rendered invisible with a five-fold reduction of apparent contrast.

Figure 1. General room layout. Left panel depicts the glare only condition, while the right panel depicts the glare plus haze condition.

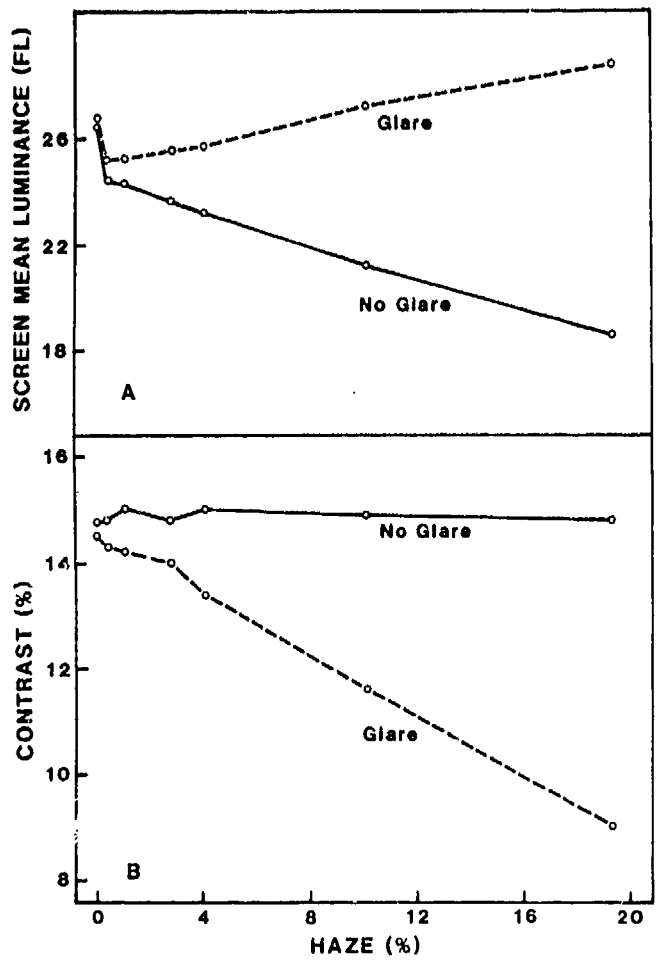

Figure 2 (A). Mean screen luminance measured with the hazy transparencies. (B). Calculated contrast based on luminances made with the hazy transparencies.

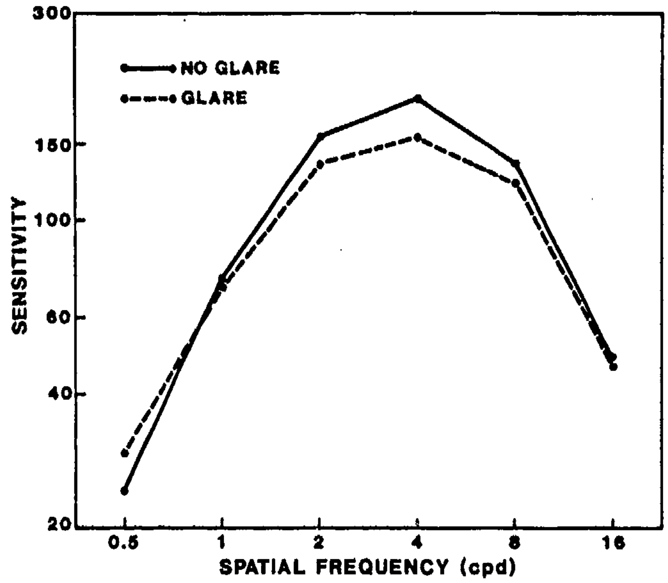

Figure 3. Contrast sensitivity as a function of spatial frequency obtained with and without a glare source.

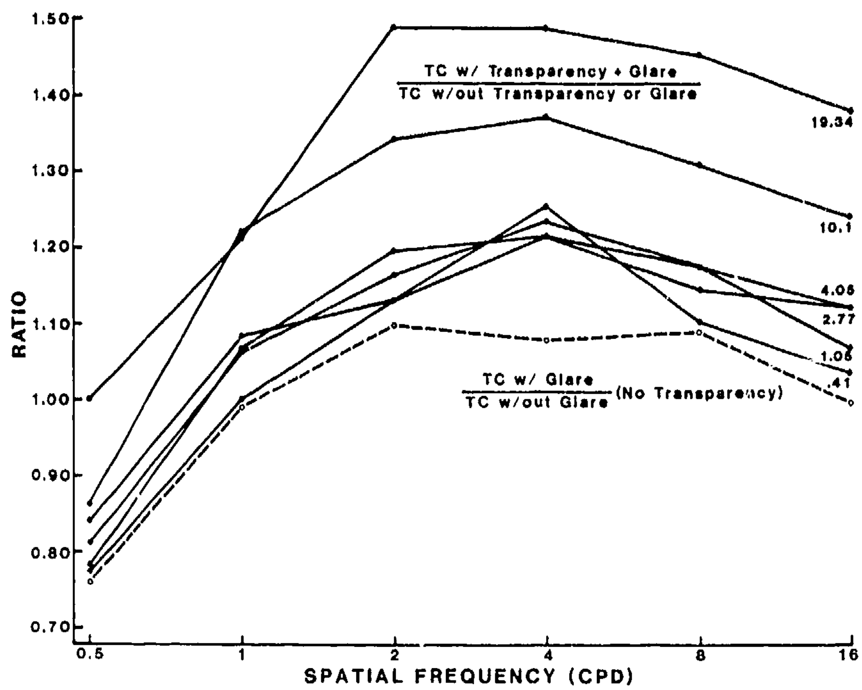

Figure 4. Ratio of threshold contrast (TC) with glare to threshold contrast without glare as a function of spatial frequency (dashed line) and ratio of threshold contrast with haze and glare to that with neither haze nor glare.

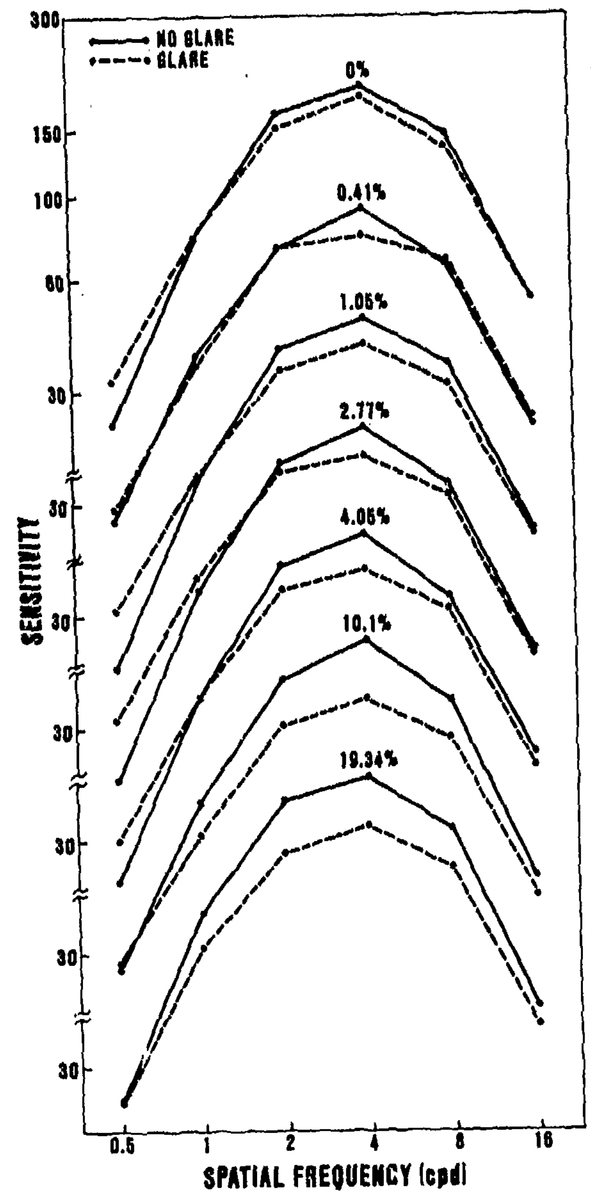

Figure 5. Contrast sensitivity as a function of spatial frequency obtained with and without a glare source for seven levels of transparency haze.

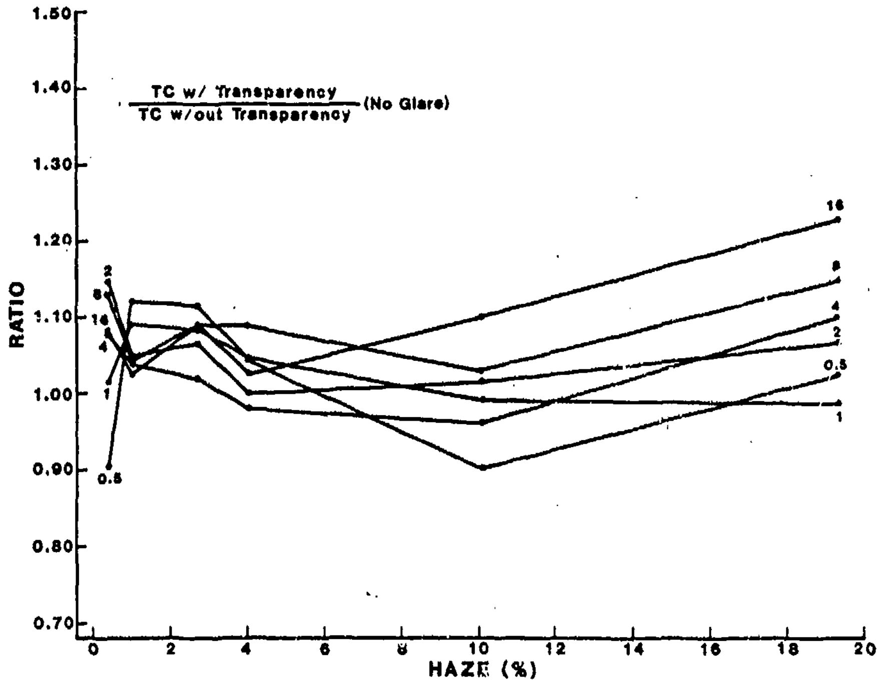

Figure 6. Ratio of threshold contrast with haze to that without haze as a function of haze level.

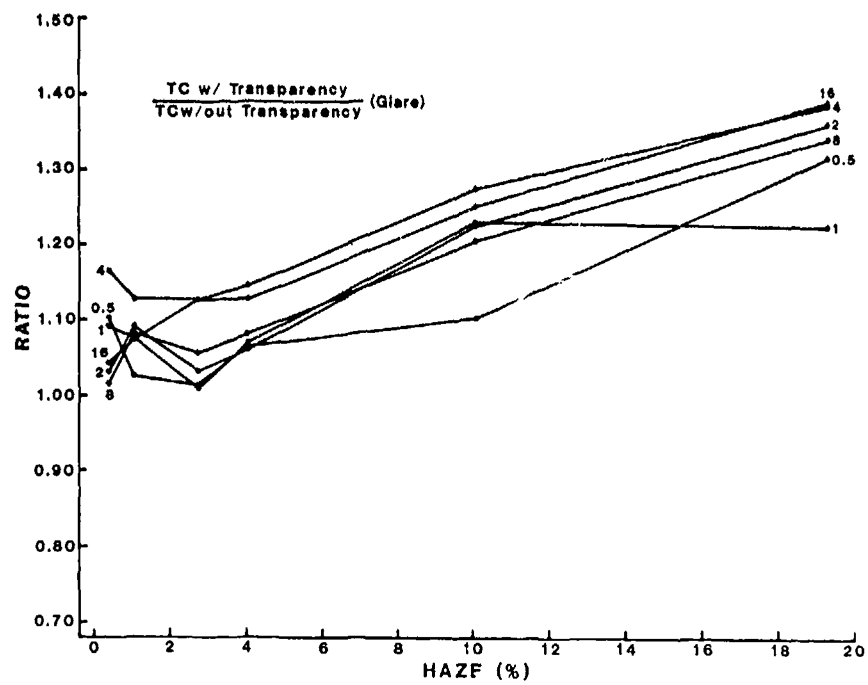

Figure 7. Ratio of threshold contrast with haze and glare to that with glare only as a function of haze level.

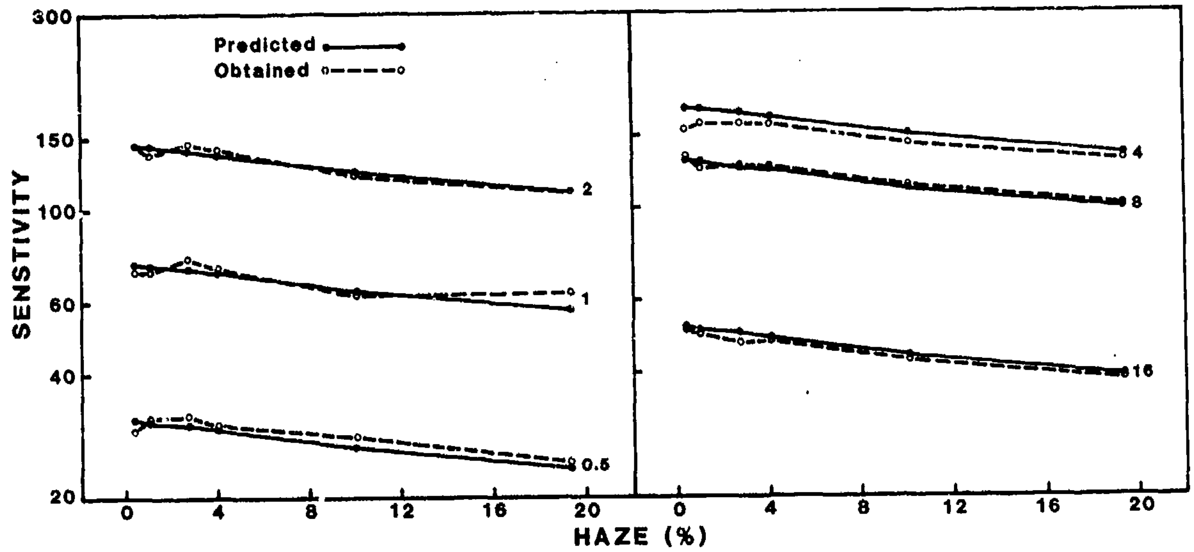

Figure 8. Predicted and obtained contrast sensitivity as a function of haze level.

REFERENCES

1. Kay, B. F. 1979. Helicopter Transparent Enclosures. Vol. II-A General Specifications. Army Research and Technology Laboratories, Fort Eustis, VA, USARTL-TR-78-25B.

2. Corney, N. S. 1973. Optical requirements for aircraft transparencies. In: Conference on Transparent Aircraft Enclosures. Air Force Materials Laboratory, Wright-Patterson Air Force Base, OH, AFML-TR-73-126.

3. Grether, W. F. 1973. Optical factors in aircraft windshield design as related to pilot visual performance. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, AMRL-TR-73-57.

4. Clark, B. A. J. 1979. Veiling glare from spectacles and visors in aviation. Aust. J. Optom. 62:342-347.

5. Glover, H. C. 1955. Light transmission and haze requirements for transparent enclosures. Wright Air Development Center, Wright-Patterson Air Force Base, OH, WADC Technical Report 55-55.

6. Shannon, R. R. 1978. Tolerance for XM29 Mask Production. Addendum to Letter, DRDAR-CLW-P, Chemical Systems Laboratory, Aberdeen Proving Ground, MD, 16 Nov 78, Subject: New Protective Mask, XM29, CARDS 1241.

7. Kay, B. F. 1978. Design, test, and acceptance criteria for helicopter transparent enclosures. Army Research and Technology Laboratories, Fort Eustis, VA, USARTL-TR-78-26.

8. Kama, W. N., L. V. Genco, M. A. H. Barbato, and M. D. Hausmann. 1983. The effect of haze on an operator's visual field and his target detection performance. Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, AFAMRL-TR-83-066.

9. Holladay, L. L. 1926. The fundamentals of glare and visibility. J. Opt. Soc. Amer. & Rev. Sci. Instr. 12:271-319.

10. Wolbarsht, M. L. 1977. Tests for glare sensitivity and peripheral vision in driver applicants. J. Safety Res. 9:128-139.

11. Sturgis, S. P. and D. J. Osgood. 1982. Effects of glare and background luminance on visual acuity and contrast sensitivity: Implications for driver night vision testing. Hum. Factors 24:347-360.

12. Hess, R. F. and L. F. Garner. 1977. The effect of corneal edema on visual function. Invest. Ophthalmol. Vis. Sci. 16:5-13.

13. Hess, R. and G. Woo. 1978. Vision through cataracts. Invest. Ophthal. Vis. Sci. 17:428-435.

14. Arden, F. P. 1978. The importance of measuring contrast sensitivity in cases of visual disturbance. Br. J. Ophthalmol. 62:198-209.

15. Paulsson, L. E. and J. Sjostrand. 1980. Contrast sensitivity in the presence of a glare light: Theoretical concepts and preliminary clinical studies. Invest. Ophthal. Vis. Sci. 19:401-406.

16. Vaegan and B. L. Halliday. 1982. A forced-choice test improves clinical contrast sensitivity testing. Br. J. Ophthalmol. 66:477-491.

17. Higgins, K. E., M. J. Jaffe, N. J. Coletta, R. C. Caruso, and F. M. de Monasterio. 1984. Spatial contrast sensitivity: Importance of controlling the patient's visibility criterion. Arch. Ophthalmol. 102:1035-1041.

18. Ginsburg, A. P. 1984. A new contrast sensitivity vision test chart. Am. J. Optom. & Physiol. Optics. 61:403-407.

19. Carney, L. G. and R. J. Jacobs. 1984. Mechanisms of visual loss in corneal edema. Arch. Ophthalmol. 102:1068-1071.

20. Miller, D. and G. Benedek. 1973. Intraocular Light Scattering Theory and Clinical Application. C. C. Thomas, Springfield.

21. Miller, D., M. E. Jernigan, S. Molnar, E. Wolf, and J. Newman. 1972. Laboratory evaluation of a clinical glare tester. Arch. Ophthalmol. 87:324-332.

22. Ginsburg, A. P. and M. W. Cannon. 1983. Comparison of three methods for rapid determination of threshold contrast sensitivity. Invest. Ophthol. Vis. Sci. 24:798-802.

23. Davis, E. T. and N. Graham. 1981. Spatial frequency uncertainty effects in the detection of sinusoidal gratings. Vis. Res. 21:705-712.

24. Owsley, C., R. Sekuler, and D. Siemsen. 1983. Contrast sensitivity throughout adulthood. Vis. Res. 23:689-699.

25. Finlay, D. and J. Wilkinson. 1984. The effects of glare on the contrast sensitivity function. Hum. Factors. 26:283-287.

26. Campbell, F. W. and D. G. Green. 1965. Optical and retinal factors affecting visual resolution. J. Physiol. 181:576-593.

27. Cohen, R. W., C. R. Carlson and G. S. Cody. 1976. Image Descriptors for Displays. Office of Naval Research, Arlington, VA, ONR-CR213-120-2.

28. McCann, J. J. and J. A. Hall, Jr. 1980. Effects of average-luminance surrounds on the visibility of sine-wave gratings. J. Opt. Soc. Am. 70:212-219.

29. Van Ness, F. L. and M. A. Bowman. 1967. Spatial modulation transfer in the human eye. J. Opt. Soc. Am. 57:401-407.

30. De Valois, R. L., H. Morgan, and D. M. Snodderly. 1974. Psychophysical studies of monkey vision - III. Spatial luminance contrast sensitivity tests of macaque and human observers. Vis. Res. 14:75-81.

NIGHT VISION GOGGLES IN ARMY AVIATION

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SUMMARY

This paper is primarily for general information on night vision goggles rather than a specific research project.

During this presentation, I will discuss night vision goggles (NVG) in Army aviation and briefly cover how they work, performance characteristics, differences in designs, research conducted with the NVG at the U.S. Army Aeromedical Research Laboratory, and present problem areas.

BACKGROUND

It all began in World War II with infrared (IR) sniper scopes. These systems were active, i.e., an IR search light was required to provide sufficient energy to produce a usable picture. At the end of the war, a fighter aircraft actually was landed at night on a blacked-out aircraft carrier using a prototype binocular IR goggle. In Vietnam, the first generation of starlight scopes was utilized effectively in taking the night advantage away from the enemy. Unlike their IR predecessors, this technology was passive by amplifying the available moon and star illumination. A characteristic of first-generation image intensification tubes was "shut down", where the tube temporally turned off if exposed to a sufficiently strong light source in order to protect the electronics and prevent damage to the phosphor screen. The first binocular goggle version was called the SU-50, and was actually used in some rescue attempts and special operations in Vietnam.

The second-generation NVG were made smaller and lighter by using a microchannel plate which incorporated circuitry to limit the gain on the image amplification when exposed to bright lights without turning the goggles off. This goggle was designated AN/PVS-5 or later the 5A, and was intended for ground use. However, Army aviation adopted this goggle in the mid-70s as an interim measure until an aviator version and third-generation technology could be fielded. The major improvements from the second- to the third-generation image intensifier tubes are the more efficient photocathode materials, increased line pairs per millimeter, and the elimination of the fiber optic image inverter. The third-generation tubes have an increase in light amplification, better resolution, less weight, and more near infrared response than the second-generation tubes.

Fig. 1 is a schematic of an image intensifier system; Fig. 2 is a second-generation image intensifier tube. The objective lens focuses an image on a fiber optic plate containing the photocathode which then converts photons to electrons. The electrons are amplified with the microchannel plate and activate the phosphor screen which converts electrons back into photons. The image is inverted with a twisted fiberoptic bundle and viewed with the eyepiece lens.

TYPES OF NVG DESIGNS

Some of the different types of NVG and devices are the AN/PVS-5, AN/AVS-6, AN/PVS-7, Model 909, Mark II "cat eyes", German goggles, and the pilot night vision system (PNVS). The AN/PVS-5 is a second-generation goggle and over 20,000 have been issued to ground and air units. The modified faceplate for the AN/PVS-5 was approved in 1982 to provide unaided look-under and look-to-the-side capability for aviation use. The AN/AVS-6 is called the Aviator Night Vision Imaging System (ANVIS). This goggle uses third-generation tubes, a dual battery pack, and a 10 G binocular assembly separation feature. Initial production of ANVIS is expected later this fiscal year. The AN/PVS-7 is a NVG in the development phase and is intended to replace the AN/PVS-5. It uses a single second- or third-generation image intensifier tube with binocular viewing to reduce the cost and weight. The 909 NVG is based on the AN/PVS-5, but uses improved second-generation tubes and optics. A limited number of these goggles were procured for evaluation purposes. The Mark II "cat eyes" are a prototype British goggle that uses a beamsplitter before each eye to provide an unaided look-through capability. German aviator NVG are similar to our ANVIS with second-generation tubes in the BM8028A and third-generation tubes with the prototype BM8043.

The PNVS is a part of the AH-64 Apache helicopter and uses infrared or temperature differential to form an image. This infrared image is displayed on a one-inch diameter cathode ray tube, which is magnified with the optics of the helmet display unit (HDU) and reflected with unity magnification from a beamsplitter or combiner lens before one eye. The IR sensor is slewed in conjugate with helmet motion.

PERFORMANCE CHARACTERISTICS

Some of the typical visual characteristics of second-generation NVG are 1200 X light amplification, maximum resolution of approximately 20/50, 40 degree circular field of view, and monochromatic vision. The photocathode of second-generation tubes is sensitive to electromagnetic energy from .400 to .900 micron (Fig. 3).

Third-generation goggles have a light gain of over 2000 and resolution of approximately 20/40. The field of view is the same as the second-generation goggles. They are sensitive to energy in the .550 to .900 micron range. The PNVS can detect a temperature differential of less than one degree, and the resolution is approximately 20/40. The field of view is 40 degrees horizontally and 30 degrees vertically. Sensitivity for the PNVS is in the 7.5 to 12 micron range.

RESEARCH WITH NVG

Some of the areas of investigation with AN/PVS-5 NVG at USAARL and a brief description of the results follow: (a) Visual acuity (V.A.) was measured through the NVG, and astigmatism of 1.00 diopter or more reduced V.A. from 20/50 to 20/60 or worse. Approximately 4 percent of the Army aviation population has 1.00 diopter or more of astigmatism. (b) Contrast sensitivity was measured with the NVG and unaided eye at various ambient illuminations (1). At 100 percent moon illumination, the unaided eye showed better contrast sensitivity at high spatial frequencies (>10 cycles/degree) and the NVG showed better sensitivity in the low and medium spatial frequencies (1-8 cycles/degree). (c) Depth perception was measured with and without the NVG in the laboratory at 20 feet and in the field from 200 to 2000 feet (2). At 20 feet the linear target separation threshold was increased approximately 3.5 times with NVG under full moon illumination compared to unaided vision under photopic conditions. In the field, the separation threshold was increased approximately 1.6 times with NVG compared to unaided day vision. (d) The state of dark adaptation was measured while using the NVG (3). Approximately 1 log unit of adaptation was lost and recovery to nongoggle threshold required approximately 3 minutes. (e) Ten pilots flew with full faceplate and noncounter-weighted NVG for 6 hours (4). No significant measurable flight performance loss was recorded. However, two of the pilots did not complete the study. One was withdrawn at 3.5 hours with tremors of the extremities, and the other withdrew at 5 hours from extreme discomfort. Postflight questionnaire responses revealed a concern with lack of concentration and a decline of mental alertness with extended wear of NVG. (f) Pilots evaluated a bifocal NVG in two separate studies before blue-green cockpit lighting had been fielded (5). The results indicated the bifocal NVG reduced workload and increased the time available of viewing outside the cockpit. (g) After a midair collision in the traffic pattern with NVG, it was apparent that the restriction to only 40 degrees of aided peripheral vision was an unacceptable safety hazard in high density flight areas (6) USAARL designed, developed, and evaluated a modified faceplate for the NVG which has been implemented by all three services. (h) Corrective lenses can be worn with the modified faceplate NVG and ANVIS. Polycarbonate, plastic, and standard tempered glass lenses were evaluated for fracture resistance when impacted with the eyepieces of NVG. A drop of the headform from 6 to 18 inches shattered plastic and glass lenses. No failures of polycarbonate lenses were recorded with drops of 6 feet. (i) Day training filter concepts and specifications were developed and evaluated at USAARL (7). These filters are used for some of the initial NVG training for the student.

PROBLEM AREAS

Some of the persistent problems with NVG include the following: excessive head supported weight and shift in center of gravity; delays in fielding the ANVIS; navigation; cockpit and position lighting compatibility; stage field lighting; lack of user's ability to adequately evaluate NVG prior to flight; weather and ambient light determinations; inadequate resolution for stand-off detection and identification; hardening from potential countermeasures; monochromatic vision with the probability of encountering inadequate contrast to avoid an obstacle; reduced field of view which reduces detection and increases workload and vertigo; inadequate training and equipment for all units; and insufficient command supervision and participation.

CONCLUSIONS

In the last 10 years, in spite of the problems with NVG in aviation, the Army has made tremendous gains in its night fighting capabilities. Every student aviator now going through pilot training at Fort Rucker, AL, is given approximately 3 hours of ground instruction and demonstration on night vision, 8 hours of academics in NVG, 12 hours of unaided night flight and 17 hours of NVG flight training before graduation. Almost all of our aircraft have been modified for compatibility with NVG. Advanced NVG training is tactical with multiple aircraft at nap-of-the-earth altitudes. The present night vision devices and the Army's night fighting still fall short in actually turning night into day. However, an adversary not equipped and trained with night vision devices could become rapidly paralyzed with fear as his forces quickly become casualties of the dark from an enemy that is not seen. He can not hide himself or his equipment, nor will he find any avenues of escape. With helicopters and night vision devices, forces can be deployed a sizeable distance into enemy territory and, undetected, attack from any direction. Such an attack at night could cause the enemy to panic and literally destroy itself.

Examples of successful use of NVG are the British expedition in the Falkland Islands, and the Israeli action in Lebanon. An unsuccessful example might be the Iranian hostage rescue attempt, and to some extent the failure to attack at night in Grenada. We must be masters of the dark. This is where high technology, training, and research can be one of the biggest force multipliers. It is imperative that units establish communication in research efforts, lessons learned, training and doctrine on a tri-service level in order to prevent reinventing the wheel, and to reduce the number of NVG training accidents.

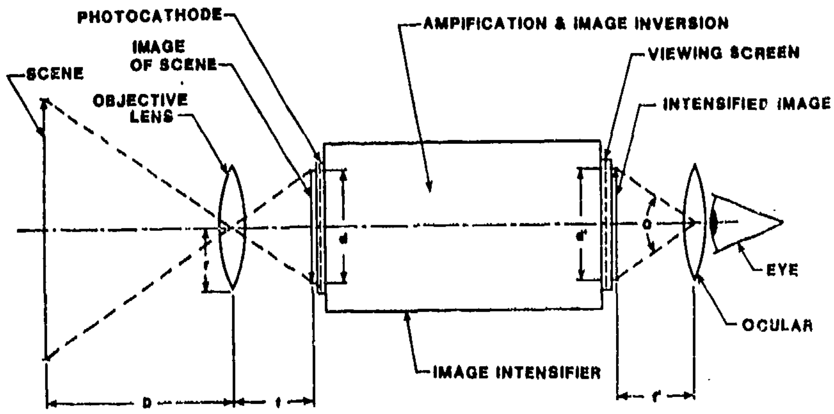
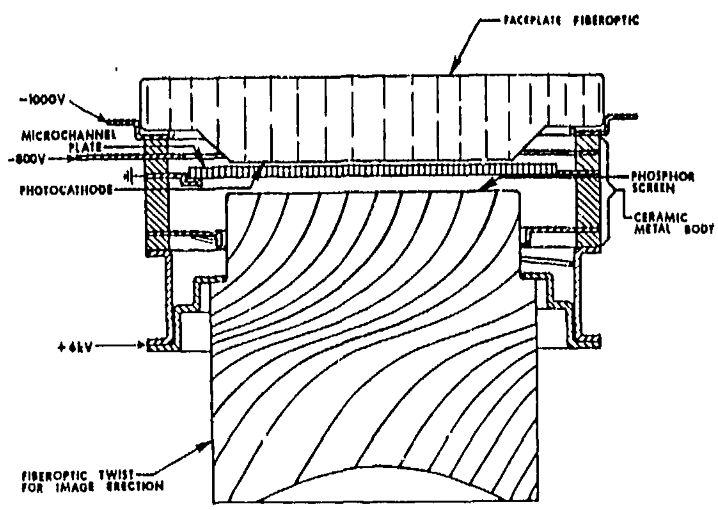


DIAGRAM OF AN IMAGE INTENSIFIER SYSTEM

Figure 1.

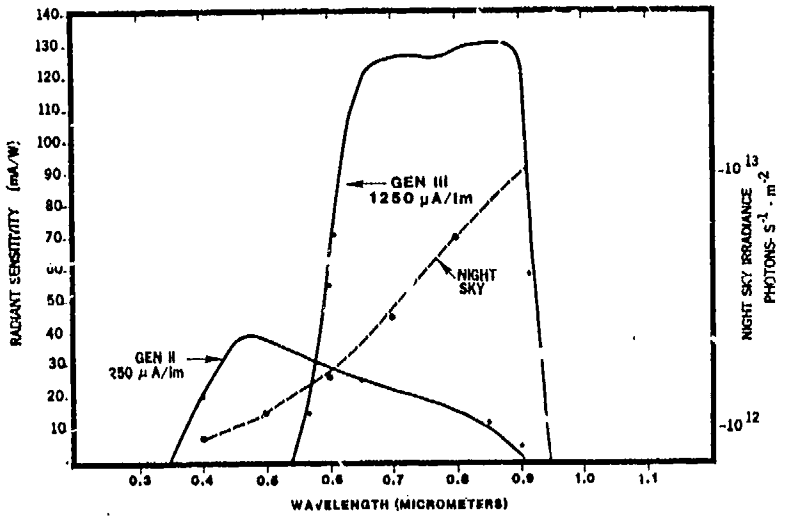
(Courtesy of Night Vision and Electro-Optics Laboratory, Fort Belvoir, VA)



THE GENERATION II IMAGE INTENSIFIER 18mm GOGGLE TUBE

Figure 2.

(Courtesy of Night Vision and Electro-Optics Laboratory, Fort Belvoir, VA)



COMPARISON OF SENSITIVITIES BETWEEN GEN II AND GEN III PHOTOCATHODES

Figure 3.

(Courtesy of Night Vision and Electro-Optics Laboratory, Fort Belvoir, VA).

REFERENCES

1. Wiley, R. W., D. D. Glick, and F. F. Holly. 1983. AN/PVS-5 night vision goggles. U.S. Army Aviation Digest. 29(5):7-11.

2. Wiley, R. W, D. D. Glick, C. T. Bucha, and C. K. Park. 1976. Depth perception with the AN/PVS-5 night vision goggle. USAARL Report No. 76-25.

3. Glick, D. D., R. W. Wiley, C. E. Moser, and C. K. Park. 1975. Dark adaptation changes associated with the use of the AN/PVS-5 night vision goggles. USAARL Letter Report No. 75-2-7-2.

4. Stone, L. W. and C. E. Duncan. 1984. Effects of extended use of AN/PVS-5 night vision goggles on helicopter pilots' performance. USAARL Report No. 84-3.

5. Stone, L. W., M. G. Sanders, D. D. Glick, R. W. Wiley, and K. A. Kimball. 1979. A human performance/workload evaluation of AN/PVS-5 bifocal night vision goggle. USAARL Report No. 79-11.

6. McLean, W. E. 1982. Modified faceplate for AN/PVS-5 night vision goggles. USAARL Report No. 83-1.

7. Behar, I. 1977. Night vision goggle, AN/PVS-5, modification for daytime training. USAARL Letter Report No. 77-7-7-2.

DISCUSSION

DR. OWENS: I have a question for Dr. Monaco. You measured accommodative performance and compared that with detection performance in your study. Your measure of accommodative flexibility was the time required to go from far to near. Is that correct?

DR. MONACO: That is right.

DR. OWENS: I am curious, first of all, about whether you looked at the time required to go from near to far. It seems that may also be important when a pilot is trying to get out of the cockpit with his eyes.

The other question is with regard to the dark focus. I have been studying dark focus of college students for a long time. I think that, perhaps, the military population is different, and I am curious about what the average dark focus was and variability of it.

DR. MONACO: In answer to your first question about the accommodative flexibility, the answer is "yes" near to far and far to near are equally important. What we were trying to ferret out by going from far to near is our belief that accommodative flexibility requires more of a demand to bring accommodation into play than to relax accommodation. Since we had a limited amount of time to administer the tests, that is the choice that we made, but accommodative flexibility in both directions is very important.

DR. PITTS: Both are correlated, far/near, near/far. You can get away with measuring one to predict the other.

DR. MONACO: The dark focus issue is something that we are going to discuss today. Dr. Morey is going to be summarizing some of the dark focus data that we have collected from aircrews at Oceana, Virginia. These are important questions and issues, but the only way that we can get at something like this is by going there and doing it.

DR. ADAMS: I have a procedural question about how you measured accommodative flexibility. You have them go from distant to near and you are working with a suprathreshold Landolt C and with a mean threshold of less than a third of a second. Were the pilots really needing to accommodate in order to make this suprathreshold decision? In other words, how do you know that they were using accommodation in order to make that decision?

DR. MONACO: That is a good question. The size letter that we used was a 20/40 Landolt C, which, in this population, would not have seriously tapped the accommodative effort. For that reason, the measure of accommodative flexibility may be some intermediate position where the pilot focused and simultaneously picked up both the distant and near target. That issue is something that will be addressed when we go back up to Oceana.

DR. ADAMS: There would be just two comments about that: Could they see a 20/40 letter without any accommodation at near? That would give me a little bit of perspective of what the likelihood is that they were even needing to accommodate. Secondly, the time is so short. This measure may be purely a reaction time. Not only would they have to respond to accommodation, which we know is a little sluggish and has a long latency, but they also have a reaction time. Together the measures provide a threshold time of .29 seconds. This makes one a little suspicious that they are actually having to accommodate at all.

DR. MONACO: Certainly, the spot detection test probably would not have given us the kind of acuities that we were getting at that range if we hadn't given the subject a pre-fixation clue. All of the visual threshold measures that we have here, in fact, are threshold measures. They are done at very high contrast. They are done with incredible illumination differences that were mimicking what we felt were air-to-air environmental conditions. So, these are points that we must consider in field data collection.

DR. LEIBOWITZ: I want to ask Dr. Regan a question. One of the themes of this symposium is night vision. I was wondering, in your studies of motion and depth, whether you did low level illumination as well as high level?

DR. REGAN: Inadvertently, in the early studies we were using oscilloscopes, which weren't very bright. Later on we got better ones, about ten times brighter, and it didn't really make any difference to the conclusions. I should mention that we have recently done some studies in Rotterdam measuring binocular eye movements with the magnetic coil method while at the same time measuring sensitivity to motion and depth, and they genuinely were taken right down to night vision levels. The purpose of the study was to compare binocular eye movements with actual retinal image position and perceived motion. If I recollect, out of that came the point that things work--the motion in depth system for stereo seems to work down to near threshold levels.

DR. ADAMS: I have a question for Dr. Behar. You had an interesting result at low spatial frequencies in your haze study, .5 cycles per degree. You got an improvement in contrast sensitivity by about 10 percent in the presence of haze. You indicated you might have had an explanation for that. I wondered what it was, and if you didn't have one, I was going to propose one.

DR. BEHAR: Maybe we can come to some truth between us. When the glare source is on, a number of things change. One of them is the diameter of the pupil; another is the state of adaptation of the eye; there are other things in addition. These were the first and most obvious things that we looked at. When we looked at the pupil size under the conditions without glare, the average pupil size was something over 5 mm, about 5.2 mm. When the glare source was turned on, the pupil was reduced to about 3.5 mm, a more optimal size for resolution. We found that, in fact, our improvement was at the low spatial frequencies where resolution is not important. It may account for the smaller glare effect for 16 cycles per degree, but not for the reversal or the improvement with the glare source. So, we don't think the pupil or pupillary size has anything to do with it.

There have been a number of classical studies which demonstrate that visual acuity improves if you increase the luminance of the surround of the acuity target up to the level of the target luminance. There have also been some studies that have demonstrated essentially the same thing with contrast sensitivity. In the absence of glare, we were studying contrast sensitivity with a display against a homogeneous background of darkness and we had a relatively low sensitivity at our lowest spatial frequency under those conditions. Two studies--I would have to get back into my paper to give you the authors--have demonstrated that if you provide a luminous surround to your display, which is equal to or somewhat close to the display luminance, the sensitivity is markedly improved over what it is when you have a background which is dark.

So, that can be accounted for by two factors. One, again, is the adaptation of the eye. If you bring the retinal adaptation up to something closer to the target display luminance, you may get some improvement. When you provide a homogeneous background that is at the same luminance to the display, the low spatial frequency in the display can operate, can break through. In order to separate which is the factor affecting resolution, sensitivity at .5 cycles per degree, we in a sense replicated a study that someone else had done.

The previous study looked at flanking fields; that is, instead of having a surround which completely encompassed the display, they had flanking fields either to the left and right of the display or top and bottom. In both cases, you would get an increase in the state of adaptation of the retina, but in the first case you would have a flanking field which is in the direction of the sinusoid, which would in a sense disrupt that low frequency fourier component. Contrast sensitivity was found to be improved compared with darkness when the flanking fields were left and right, but not when they were top and bottom. So, I suspect that by simply having some luminance in the direction of the sinusoid, you improve sensitivity because of the Fourier analysis which the eye is doing. What was your explanation?

DR. ADAMS: I think I like yours better. However, mine was simply that when you increase the average luminance of the field, we know that contrast sensitivity improves. This is what I think you are referring to as the adaptation level. So, if you get a reduction for high spatial frequencies selectively from glare, then the amount that you go down from the glare is great at all frequencies except the low one, which is not as bothered by glare. The elevation that you get at all spatial frequencies due to the average luminance increase is essentially washed out by the glare at medium and high spatial frequencies and not washed out at low spatial frequencies. So, it is showing its head above the noise at low spatial frequencies only.

DR. REGAN: Perhaps I could make a comment on a point which occurred in LCDR Heatley's presentation. For example, the illustration of the tiger, if the tiger stands still and it is perfectly camouflaged, it is invisible. That could correspond to the case of a small black dot of an aircraft against a rather textured scene, perhaps very black and white clouds or the ground. As soon as the tiger starts to move, it is visible. That could correspond to the way in which a small black dot is visible when moving across the textured ground. I think it may well be the case that those two forms of breaking camouflage, raising the contrast of a static target or moving it, activate totally different subsystems in the human visual system, and that it is not possible to predict visibility of a moving target of that type from acuity, spatial contrast, or static measures, because they may use totally different systems.

In particular, it may be that in order to know whether somebody has a good sensitivity for a black dot moving across a textured background you would have to measure something just like that, and if you wish to know whether they have a good sensitivity for a target which is slightly different contrast but can be seen statically, a relevant measure of contrast sensitivity would tell you that.

I think that this issue is hardly discussed in the vision psychophysics literature. If one looks at the current models of how to extract figure from ground through motion, it works quite differently than the type of work currently going on about how to extract figure from ground by luminance. The research groups pursuing that at M.I.T. and elsewhere are not considering this other question. The dot moving across the textured background involves motion detectors in individual pathways. The edge is detected by motion detectors, not contrast detectors because it is not there, and the motion detector's outputs are summed by a rather large pool of cells. An object is an area of coherent motion and the boundary is an area where the motion vectors change. That type of edge detection can produce very sharp edges; it can also fail to produce high acuity. A periodic target like a grating defined by motion might be invisible, but you might see quite sharp edges off a small moving object.

It is a different system altogether, and the measurements in the human visual system on objects made visible by luminance contrast and objects made visible by motion contrast indicate that the temporal and spatial summation for these two forms of vision are wildly different. For example, temporal summation for an object you see because it is brighter is classically about 60 milliseconds. For an object seen by motion, it can be three-quarters of a second, indicating a totally different mode of operation.

When one has that type of aircraft target, either against a clear sky or against a textured background, it could be that you are dealing with two totally different visual processes.

DR. PITTS: Incidentally, this is so, because you can demonstrate it electrophysiologically if you take a primate and do a lesion in vision area 4 or 5, not 1, 2, or 3. If you can pick out a particular cell, then later on, you can prove that the animal is completely blind to motion, not blind to contrast and not blind to the normal luminances that we think about, but completely blind to motion. In other words there is electrophysiological and neurophysiological evidence for just what you are talking about.

II. NIGHT VISION IN AVIATION

DARK FOCUS, ACCOMMODATIVE FLEXIBILITY AND FLIGHT PERFORMANCE

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SUMMARY

The Naval Aerospace Medical Research Laboratory (NAMRL) is currently engaged in the development and validation of various performance-based psychological and physiological tests, which eventually will be applied to assessment, selection, classification, and retention standards of naval aircrew. A statistical approach is used to examine the relationship between night carrier landing (NCL) performance and the vision test variables, dark focus, and accommodative flexibility. Results indicate that both vision variables are highly correlated with NCL performance for two categories of aviators.

INTRODUCTION

The dark focus (DF) value is a measurement of the resting refractive state of the eye in the absence or marked reduction of external stimuli for accommodation. As light levels are reduced, accommodation shifts from a focus appropriate for the viewed object, to a position intermediate to the point of dark focus (1-3). The three types of anomalous myopia (space, night, and instrument myopia) are probably linked to the single propensity of the eye to return to a "resting" point, or "dark focus" point, in response to a general reduction in visual stimulation (4). Since NCLs are performed under environmental conditions precursory to night myopia (darkness), it was hypothesized that aviators having dark focus points in the near field would have more difficulty interpreting visual cues from the carrier deck, than would aviators having DF points closer to optical infinity.

During NCLs the naval aviator initiates his approach from a holding area located well behind the ship, called the "Marshall point" (Fig. 1). At Marshall, he is in the control zone of the ship and is under positive control. During the initial approach phase, the aviator navigates exclusively by instruments, and his visual world is effectively within 36 in. of his eyes. However, beginning about 0.75 mi aft of the carrier, the aviator visually transitions out of the cockpit to complete his final approach. At this point, he acquires the visual aid landing system (the Fresnel lens) for glideslope information, and the center line and drop lights for lineup information. He refers regularly to the angle of attack indexer lights inside the cockpit for "on speed" indications. Throughout final approach, the aviator constantly scans these three references, until touchdown and arrested landing. This scanning requires an accommodative effort from a close focal point, held over a 10-15 min period, to an entirely different repetitive and rapidly changing accommodative effort. During the final 15 to 20 sec period, the aviator must simultaneously make control adjustments, a mandatory radio call, handle turbulence, and synthesize and act on visual and auditory information.

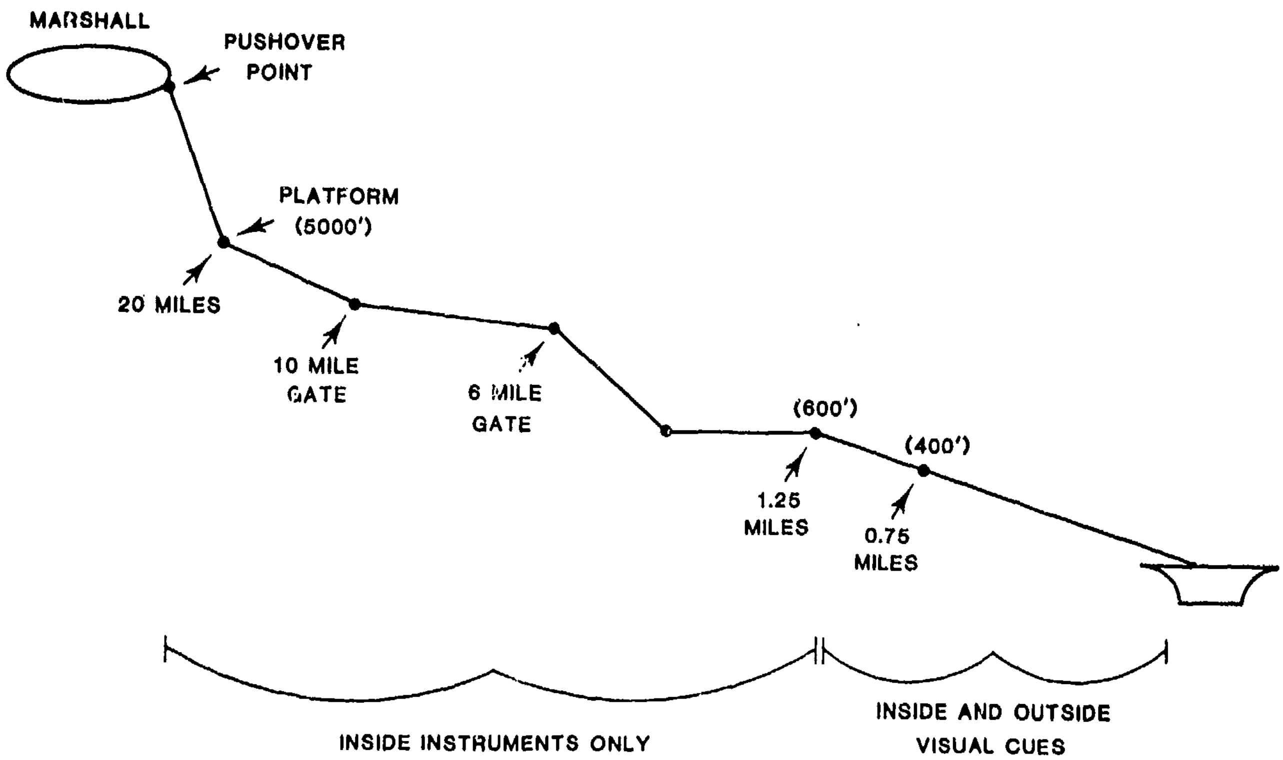

Figure 1. The naval aviator initiates his approach from a holding area located well behind the ship, called the "Marshall point."

METHODS

Data were obtained from 41 aircrew members from Fighter Wing One (FITWING ONE) at the Naval Air Station, Oceana, VA. An average NCL performance score was obtained for each aviator, based on 30 or more individual night carrier landings. The highest attainable NCL score is 4.0. A Laser-Badal Optometer was used to measure the individual dark focus values (5). The test for accommodative flexibility is part of NAMRL's automated vision test battery (6). Two variables were studied: early accommodative reaction time (A-RT) and accommodative threshold target time (A-T). The A-RT is the subject's overall response time to two Landolt C targets, one at 5.5 m (optical infinity), and the other at 0.45 m. The target sizes were well above visual threshold, and so acuity was not considered a confounding variable. Targets were presented at 1.4, 1.0, and 0.6 sec; therefore, for the A-RT, target time was not considered to be an intervening influence. The A-T was the target presentation time at the subject's threshold for correct response. The apparatus and testing procedure have been described previously (6-8). Visual acuity was measured for all participating aircrew members and found to be 20/20, or corrected to 20/20 with conventional spectacles.

RESULTS

When NCL scores were compared with DF measurements, no significant correlation was found ($r=.15$). The average NCL score was then plotted against the average DF measurement for each individual. The data were partitioned into quadrants by two perpendicular lines (Fig. 2). The horizontal line represented the mean NCL score and the vertical line represented the mean DF value.

DISCUSSION

Quadrant II displayed a significant correlation between average NCL score and average DF value ($r=0.62$; $p \leq .05$) (Fig. 2). This implies that aviators with less myopic dark focus values have better NCLs. In addition, a significant correlation was found between average NCL score and average early accommodative reaction time for the aviators of quadrant II ($r = 0.86$; $p \leq 0.01$). This may indicate that aviators with slower A-RT scores have better NCL scores. One possible interpretation may be that faster A-RT based skills may translate into abrupt or jerky piloting responses. The A-T failed to significantly correlate with NCL (QII). However, this test variable was markedly different for the aviators of quadrants II and IV. The mean A-T score for the aviators of quadrant II (above the NCL mean) was 0.33 sec which was almost twice as fast as the mean A-T score (0.60 sec) for the aviators of quadrant IV (below the NCL mean). Therefore, A-T may be useful in defining these two categories, or in predicting NCL performance.

r values

NCL --> SCORE ($\bar{X}$)		
	R^2 =.02 |	NCL DF .07 A-RT .07 A-T -.07 N1=12 I	R^2 =.75** |	NCL DF .62* A-RT .86** A-T .04 N2=9 This quadrant is above the mean for NCL and DF II
	IV R^2 =.88** |	NCL DF -.75** A-RT -.90** A-T -.05 N4=8 This quadrant is below the mean for NCL and DF	III R^2 =.27* |	NCL DF .21 A-RT .46 A-T .06 N3=12

DF SCORE ($\bar{X}$)

*Indicates significance at the .05 level.
**Indicates significance at the .01 level.

Figure 2. Average NCL score plotted against the average DF measurement for each individual.

The negative correlations of quadrant IV (Fig. 2) offer an interesting contrast to the positive correlations of quadrant II. The negative correlation between DF and NCL ($r=-0.75$; $p\leq 0.01$) suggests that aviators with more myopic DF values have better NCL scores. Initially, this negative correlation appears confusing; however, such a relationship could result from increased stress.

By partitioning the data into quadrants we may have indirectly accessed an influence of stress on NCL performance. For example, the aviators in quadrant IV may be under more stress than the aviators of quadrant II since they (QIV) demonstrated below average night carrier landing ability, more myopic DF scores, and accommodative target times (A-T) which were nearly twice as slow as the aviators of quadrant II.

Night carrier landing qualification is the most difficult and stress producing task within the naval flight training program. During the latter phase of the landing approach, the aviator primarily attends to the lighted carrier landing cues. This is an amber light, the "meatball", which appears to move relative to a fixed line of green (datum) lights representing the horizontal or horizon line (Fig. 3). The aviator's ability to visually detect and respond to gradual or subtle cue changes is critical to his landing performance. Since the A-T test score represents the average of the fastest target presentation times at which the subject responded correctly, and the "meatball" is a dynamic visual target, it was hypothesized that a relationship might exist between A-T and NCL performance.

Previous attempts to study the effects of "physical threat" on aviator performance have used various approaches, such as attempting to mimic the "stress-factor" experimentally using adversive stimuli (e.g., electric shock) (9), or developing certain perceptual psychomotor abilities to help anticipate potential flight failures (10). "Piloting-stress" resulting from awareness of a physical threat has also been studied from biochemical (11-13) and psychiatric perspectives (14,15). Previous investigations seem to indicate that stress associated with night carrier landings perhaps is greater than that experienced in wartime air-to-air combat (16). Consequently, it is hypothesized that stress, or the ability to manage stress, may have a major influence on NCL performance.

The four categories of aviators are defined statistically; stress is not accurately indexed and was not part of the original design. Also, the sample size is limited. Therefore, the following should be taken as conjecture, and not an affirmation of the hypothesis.

Based on all available information, from anecdote to biochemistry, the aviators in quadrant IV are probably under more stress than the aviators whose performances are above average. An internally or externally induced sympathetic autonomic response could account for the enigmatic reverse relationship between DF and NCL ($r=-0.75$; $p\leq 0.01$). A sympathetic norepinephrine response in the eye could relax the ciliary muscle, causing the lens to become thinner, and thereby accommodate the eye toward optical infinity (17). Existing indirect physiological evidence supports this possibility: atropine blocks the action of acetylcholine at the neuromuscular synapse, and the resulting paralysis of the ciliary muscle shifts the focus toward hyperopia. Patients suffering from Horner's syndrome (paralysis of the sympathetic supply to the head) demonstrate a shift in refraction, becoming more myopic (18). Sympathomimetic drugs, such as 10% phenylephrine, cause the refractive error to shift toward a more hyperopic direction. Moreover, sympathetic denervation or beta-adrenergic blockade with propranolol removes the inhibitory activity and accommodation increases (19). Therefore, stress could account for the enigmatic dichotomy in flight performance for aviators in quadrant IV; the worse the DF and the slower the

A-T scores, the more difficult the task and the greater the self-imposed stress, so the greater the "stress-induced" hyperopia. This may correlate with anecdotal aviator reports that the landing cues are initially "blurry or fuzzy" and then they just snap into focus." It is axiomatic in NCL that how well the aviator "sets up" (his position at 0.75 mi) usually correlates with how well he lands. If you can't "see" visual cues well enough, you reduce your chances of a good carrier landing score. Consequently, a stress-induced hyperopic shift in accommodation might enable the aviator to improve his NCL performance.

A strong negative correlation was also demonstrated in quadrant IV between NCL and A-RT ($r=-0.90$; $p<0.01$), thus implying that aviators with faster accommodative reaction time have better NCL scores. If the aviator suffers from night myopia and exhibits a slow accommodative reaction time, this may inhibit his ability to interpret subtle changes in visual landing cues with resultant decrease in NCL performance. Consequently, time-dependent visual skills may be critical to flight performance. Such a situation could explain the opposing A-RT and NCL correlations for quadrants II and IV.

The mean A-T score for the aviators of quadrant IV was 0.60 sec, while the mean A-T score for the pilots of quadrant II was 0.33 sec. Also, the mean DF score for quadrant IV was -1.20 D, while for quadrant II it was -0.17 D. Since the mean values of these two variables (DF and A-T) are so much worse for the aviators of quadrant IV than for those of quadrant II, it may mean that early in the glide slope, the aviators in QIV are markedly less adapt at focusing the carrier landing cues, and throughout the landing they are slower at identifying changes in the carrier landing cues. This may imply a night myopic-reduction in visual acuity. During a night carrier landing approach, such a situation could contribute to stress. Hence, the aviators of quadrant IV may undergo a stress response which in turn may produce the as fore mentioned stress-induced hyperopia. The stress-induced hyperopia could facilitate the aviator's monitoring of the landing cues and thereby improve his NCL performance, thus accounting for the inverse correlation between the DF values and NCL scores for the pilots of QIV.

As previously stated, the mean DF (-0.17 D) and A-T (0.33 sec) values for the aviators of QII are markedly better than those for the aviators of QIV (-1.20 D and 0.60 sec, respectively). Consequently, there is a possibility that the aviators of quadrant II see and identify the landing cues and their changes sooner. This may explain the significant positive correlation between the DF and NCL for this group (QII). The direct correlation between A-RT and NCL ($r=0.86$; $p\leq0.01$) may imply that those aviators with slower A-RT values make "smoother" flight control responses and hence, better NCL scores.

Multiple linear regressions were run on all four quadrants, individually and together, using NCL as the dependent variable, and with DF and A-RT as the independent variables. The R^2

values for quadrants II (R^2 =.75) and IV (R^2 =.88) indicate that 75 and 88 percent of the variability in night carrier landing performance be explained by these two vision measures. However, the low sample sizes in quadrants cause some artifical inflation of the R values. It is apparent that the lack of overall correlation between DF and NCL for the total group (N=41; r=.15) is an underestimation of the relationship, since opposing relationships exist in quadrants II and IV.

Additional vision and performance (NCL) data have been collected and are currently being analyzed. Studies are being designed to investigate the influence that stress may have on both vision and performance variables.

The NCL is an extremely demanding task requiring sensory adaptation, perceptual awareness, psychomotor skill, rigid discipline and self control. There is no "equivalent" or "simulant" of the conditions surrounding the night carrier landing. Understanding the factors which influence NCL require a multidisciplinary effort with constant reference to the "real world". Oversimplified approaches, particularly those limiting the nature or number of scientific disciplines involved, are doomed to failure.

REFERENCES

1. Wald, G. and D. R. Griffin. 1947. The change in refractive power of the human eye in dim and bright light. J. Opt. Soc. Am. 37:321-336.

2. Leibowitz, H. W. and D. A. Owens. 1975. Night myopia and the intermediate dark focus of accommodation. J. Opt. Soc. Am. 65:1121-1128.

3. Hennessy, R. T., J. K. Shiina, and H. W. Leibowitz. 1976. The effect of pupil size on accommodation. Vis. Res. 16:587-589.

4. Leibowitz, H. W. and D. A. Owens. 1975. Night myopia and the intermediate dark focus accommodation. J. Opt. Soc. Am. 65:1121-1128.

5. Monaco, W. A. and C. G. Knowlton. 1984. Dark focus: Intersubject variation, intrasubject stability, and relationship to near retinoscopy. NAMRL-1307, April 1984.

6. Morris, A. and J. Goodson. 1983. A description of the Naval Aerospace Medical Research Laboratory vision test battery. Aerospace Medical Association 1983 Annual Scientific Meeting, pp. 40-41.

7. Molina, E. A. 1983. Digital system controller to administer test of the vision test battery. Preprints ASMA, pp. 42-43.

8. Morris, A. and J. Goodson. 1983. The development of a precision series of Landolt ring acuity slides. NAMRL Report 1303.

9. Curran, P. M. and R. J. Wherry, Jr. 1967. Some secondary determiners of psychological stress. Aerosp. Med. 38:278-281.

10. Gibson, R. S. and L. E. Waldeisen. 1970. Perceptual psychomotor tests for predicting success in naval flight training. Paper presented at the 41st Annual Meeting of the Aerospace Medical Association, St. Louis, MO., April 1970.

11. Krahenbuhl, G. S., J. R. Marett, and N. W. King. 1977. Catecholamine excretion in T-37 flight training. Avia. Space Environ. Med. 48:405-40.

12. Krahenbuhl, G. S. and J. Harris. 1984. Biochemical measurements of the human stress response. Air Force Human Resources Laboratory, AFHRL-TR-83-40.

13. Personal communication with Dr. G. S. Kranhenbuhl at Arizona State University.

14. Reinhardt, R. F. 1965. Fear of flying. Presentation at the Ann. Meet. Am. Psychi. Assoc. May 1965.

15. U.S. Naval Flight Surgeon's Manual. Prepared by Naval Aerospace Medical Institute and BioTechnology, Inc., Contract No. N00014-76-C-1010, Bureau of Medicine and Surgery, Washington, DC, 1978, Pp. 6-1 to 6-35.

16. Roman, J., H. Older, and J. L. Walton, Jr. 1967. Flight research program: VII. Medical monitoring of Navy carrier pilots in combat. Aerosp. Med. 38:133-139.

17. Kruk, R., D. Regan, K. I. Beverly, and T. Longridge, Correlations between visual test results and flying performance on the advanced simulator for pilot training (ASPT). Aviat. Space Environ. Med. 52:455-460, 1981.

18. Cogan, D. C., Accommodation and the autonomic nervous system. Arch. Ophthalmol. 18:739-766, 1937.

19. Tornqvist, G., Effect of cervical sympathetic stimulation on accommodation in monkeys. Acta Physiol. Scand. 67:363-372, 1966.

NIGHT VISION GOGGLE (NVG) HEADS-UP DISPLAY (HUD)

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SUMMARY

Standard night vision goggles were modified to accommodate a visual display similar to that employed in aircraft Heads-Up Displays (HUDs). Primary users of this device are Military Airlift Command (MAC) pilots flying low level special operations. During use, the pilot sees a thermal image of the ground, with critical flight path and attitude information symbolically displayed on the scene. This modification allows the pilot to fly at very low levels at night without having to look inside in the cockpit. This paper relates the process of design and fabrication of the HUD optics and the selection of the heads-up symbols (e.g., airspeed, altitude, heading) for transports and helicopters. It also reports the first successful trials on a C-141B jet transport.

INTRODUCTION AND BACKGROUND

This report documents the development and first application of NVGs modified with HUD symbols for flying night, visual flight rule (VFR), low level operations. The NVG/HUD combines monocularly presented flight symbology with a binocular view of the outside scene. Development and construction of the devices associated with the NVG/HUD were performed at the Air Force Aerospace Medical Research Laboratory (AFAMRL).

The NVG/HUD is presently used by pilots flying jet and turbo-powered cargo aircraft, as well as pilots of conventional helicopters. Flight testing was performed during night sorties in South Carolina and Florida. Structured questionnaries and interviews are used to guide design changes, suggest training requirements, and assess pilot acceptance.

Characteristics and use of NVGs

Godfrey (1982) described the development and use of NVGs in military crewstations.

> "NVGs have now attained a level of sophistication such that aircraft can be safely and comfortably flown using these devices. NVGs operate by amplifying reflected low intensity visible and near infrared (invisible) light. The goggles most commonly referred to are AN/PVS-5 (Generation II) and ANVIS (Generation III) (Aviators Night Vision Imaging System). Generation II goggles can be helmet-mounted

but are rather heavy and awkward. The user must see everything through them including cockpit instrumentation. The Generation II produces a bright target image at light levels as low as quarter moon illumination. The latest NVGs (Generation III) are helmet-mounted, lightweight, and well balanced so that the person wearing them can operate unhindered. The design permits use of the goggles to produce a clear green picture of the world around, while at the same time permitting use of the naked eye to look under the goggles and read instrumentation or other information. Generation III NVGs produce a bright target image at light levels as low as starlight illumination."

As with any new technology introduced into areas as complex as an aircraft crewstation, there are a number of problems which must be resolved. The most significant problem is the light which is enhanced to produce a picture of the outside world. The wavelength of this light is between 600 to 900 nm. This means that incandescent lamps or any other light whose wavelength is longer than approximately 525 nm (green light output) will also be amplified and interfere with the image of the outside scene. Yellows, reds, and infrared either "blind" the goggles or cause them to protectively shut down much as the unaided eye adapts to very bright light. The response of these goggles is shown in Fig. 1.

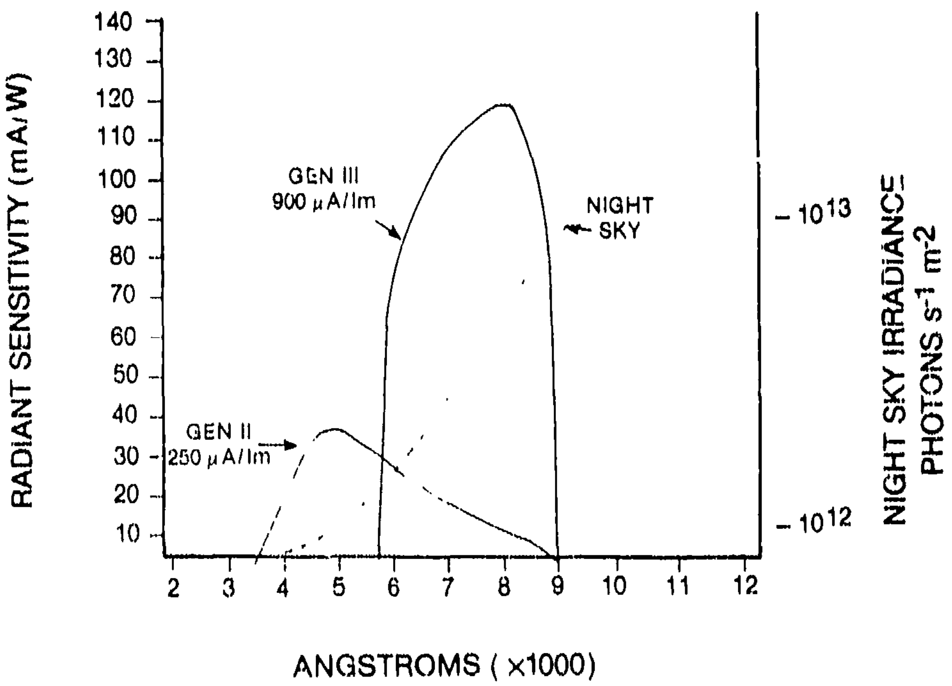


Figure 1. Response of night vision goggles.

Characteristics of the NVG/HUD

AFAMRL solved the problem of flying very low levels, at night, by providing HUD symbols on a combining glass over one of the goggle eyepieces. The concept was to provide sufficient position and attitude information to the pilot during enroute, air drop, and landing operations to allow an "eyes-out" orientation during the complete operation.

Several modes of information display are available. Fig. 2 shows the HUD symbols selected for one mode (normal) of the transport and helicopter mission. Generally, for other models such as SEARCH and LANDING, the number of symbols was reduced to avoid cluttering the center of the IR image when the pilot is concentrating on ground patterns and landmarks.

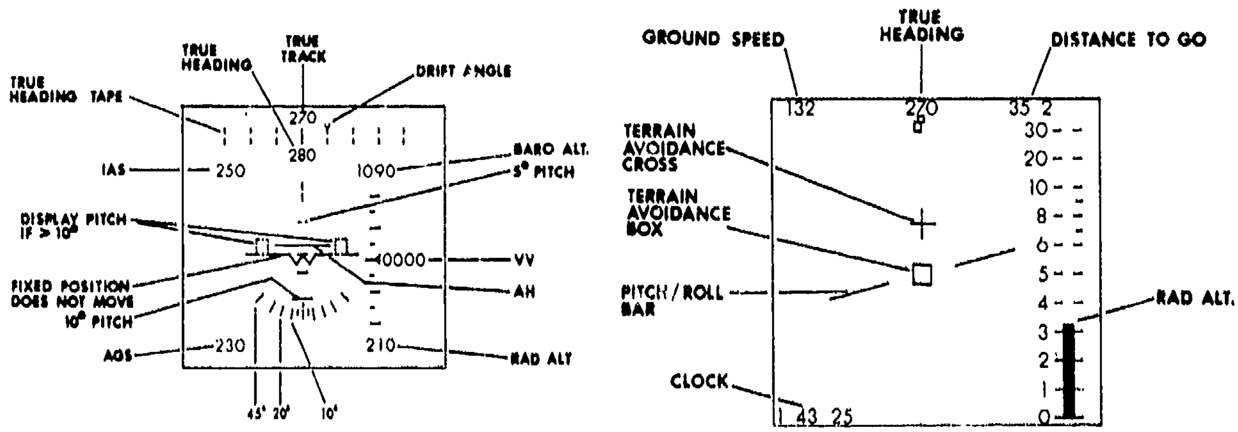


Figure 2. HUD symbols for transport and helicopters. Several special features of the symbology are indicated in Table 1.

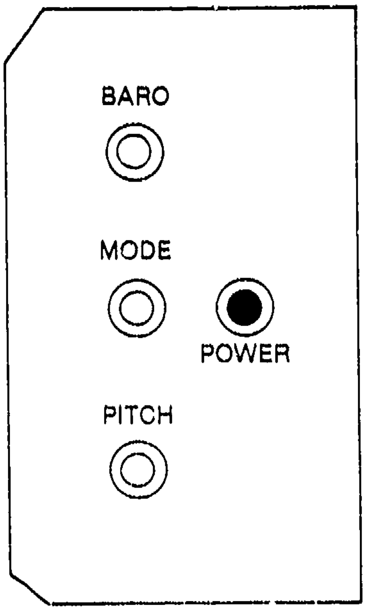
TABLE 1. Special control/display features.

Altitude	Displays barometric or radar altitude, radar changes in 10-foot increments below 1000 feet, 100-foot increments above 1000 feet.
Fixed Digit	The last zero for altitude and vertical velocity is an unchanging zero (0) to reduce distraction of a fast changing digit.
Pitch	Over 10 degrees pitch, a 10's digit is displayed to the left of the aircraft and 1's unit to the right.

The flight instrument raw signal information is collected by the aircraft's signal processing computer and converted into Arinc 429 formatted data. The data are transmitted to the AFAMRL display unit across the Arinc 429 bus.

The data unit converts the data to a symbolic display on a cathode-ray tube format. The symbology display is reflected from a front surface mirror to a relay lens which focuses onto a flexible fiber optic bundle. The bundle brings the image up to the NVG where a collimating lens moves the image or the symbology to optical infinity. This image is then reflected from a beam splitter into the NVGs. The observer sees the image of the HUD symbols superimposed over the outside view.

The controls for the HUD portion of the system are shown in Figure 3. The control panels are positioned at various locations, depending on the type of aircraft. The design goal was to include only critical pilot control functions and automate other functions (focus, brightness, contrast).



4 PUSHBUTTONS

BARO - Changes readout to match aircraft altimeter

MODE - Selects symbol set for mission segment

POWER - Turns HUD equipment ON

PITCH - Trims the aircraft symbol to horizon bar for aircraft attitude

Figure 3. Pilot's controls for transport and helicopters (tentative).

Evaluation of the NVG/HUD

Evaluation and modification of the device was iterative. The approach was to use actual flight experience to modify user HUD symbol requirements, obtain acceptance ratings for the device, and identify problems. For each aircraft, pretest discussions were held with MAC personnel to derive a symbol set that appeared to satisfy the aircraft mission requirements. Throughout the aircraft test series, the design goal was to minimize the number of symbols, modes, and controls without compromising crew safety or adding to crew workload.

HQ MAC authorized a series of evaluations based on successful trials in preliminary C-141 flights. Over a 1-year period, MAC directed that other aircraft be evaluated for NVG/HUD use:

<u>Aircraft Evaluated for NVG/HUD Use</u>

C-141B	C-130E (AWARDS)	H-53E
	MC-130E	HH-53B/C
	AC-130H	HH-53H
	HC-130	UH-60A

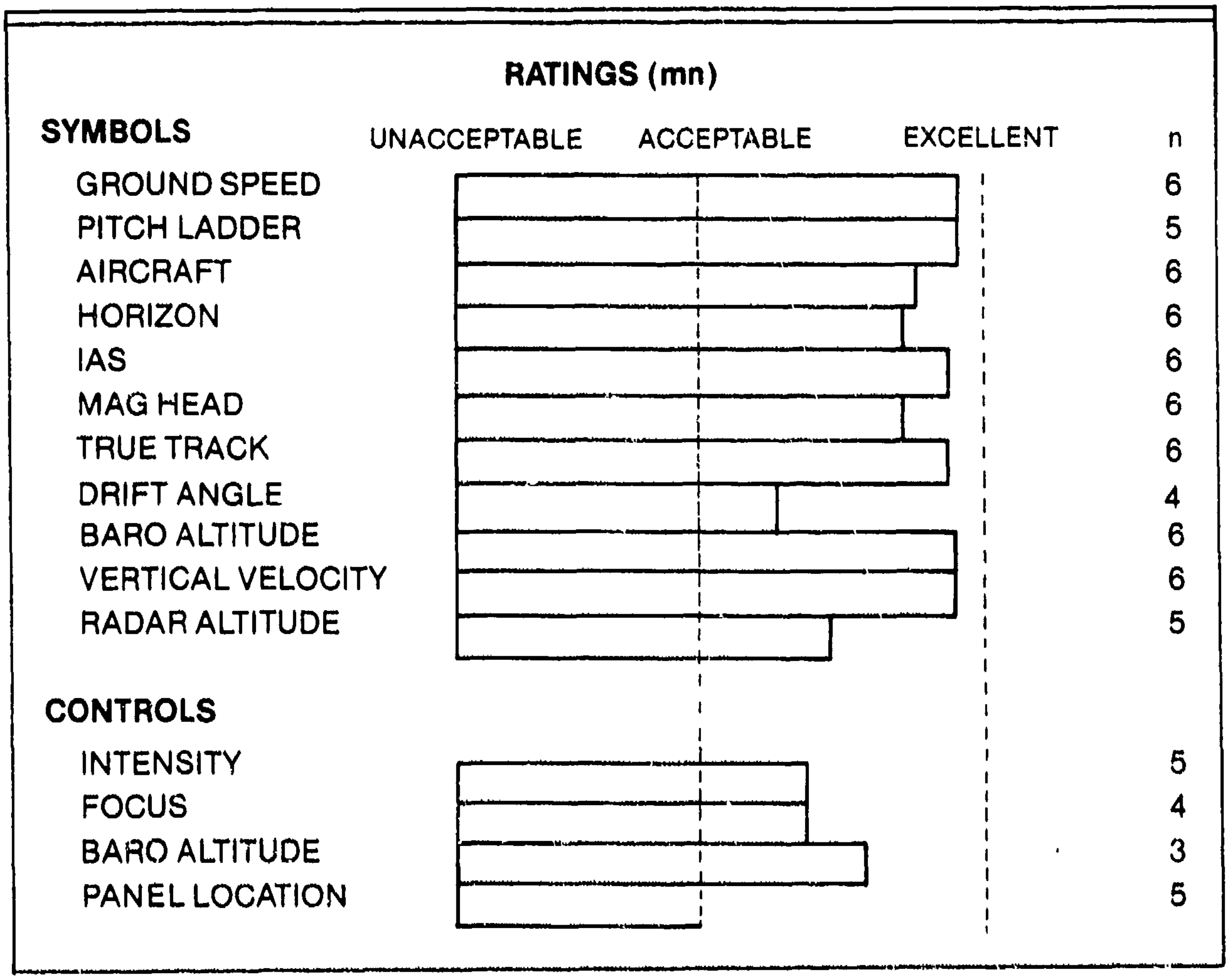
Several C-141 and C-130 crews have flown and endorsed the NVG/HUD for low level operations. Testing and evaluation on other aircraft is ongoing.

RESULTS

The four-engine heavy jet transport, C-141B, flies a low level mission that currently relies on the pilot looking outside and maintaining terrain clearance while the co-pilot looks inside and ensures the integrity of aircraft velocity and attitude. The missions include a blacked-out approach, landing, and takeoff from a remote field. The current concept (pre-NVG/HUD) is for the co-pilot and two navigators to verbally provide critical information to the pilot throughout the operation. Six C-141B pilots flew night approached and full-stop landings with the NVG/HUD. A structured questionnaire was used to obtain the pilot ratings shown in Table 2.

Using a five point scale (0=unacceptable, 3=acceptable, and 5=excellent), all HUD symbols were rated between "more acceptable" and "excellent" except for the drift angle symbol. The three system controls (to adjust intensity and focus and to reset the barometric altimeter) were rated as more than acceptable. The location of the control panel was rated acceptable; however, its relocation was recommended. Visual fatigue was rated as below average to none and display contrast as being adequate for most night sky conditions under various levels of illumination. In terms of the systems contribution to mission success, the pilots generally agreed that the NVG enhances control of the aircraft, reduces interphone communication and increases flight safety (terrain clearance).

TABLE 2. C-141B pilot ratings of adequacy of symbols and controls.



CONCLUSIONS

Modification of NVGs to provide critical flight information to MAC pilots was eminently successful. Results of this new technology are being applied to other MAC aircraft, both fixed and rotary wing. This modification can be used to improve pilot safety and performance in aircraft which are not equipped with HUDs.

REFERENCES

1. Godfrey, G. W. 1982. Principles of Display Illumination Techniques for Aerospace Vehicles and Crew Station. Revised and Expanded, 1982. Aerospace Lighting Insititute. Tampa, FL.

2. Task, H. L., D. F. Kocian, and J. H. Brindle. 1980. Helmet-Mounted Displays: Design Considerations. In: Advancement on Visualization Techniques, Hollister, W. M. (Ed.), AGARDograph No. 255, Harford House, London.

OCULOMOTOR PERFORMANCE IN LOW VISIBILITY CONDITIONS

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ABSTRACT

The efficiency of visual accommodation and binocular vergence deteriorates dramatically under low visibility conditions. When stimulation is degraded, both systems exhibit progressive biases toward the observer's characteristic resting state, which typically corresponds to an intermediate distance. Thus, the amplitude or operating range of these adjustments collapses, with the far point approaching and the near point receding toward the intermediate resting position. These normal variations of oculomotor behavior can seriously impair one's ability to detect, identify, and localize visual stimuli (1). This paper reviews research on the resting state, or dark focus, of accommodation. Optical corrections based on the individual's dark focus have been found to eliminate "night myopia" and "empty-field myopia," providing significant enhancements of detection, acuity, and contrast sensitivity. Current research indicates that the optimal correction for such anomalous refractive errors may also depend on the observer's oculomotor responsiveness to sensory input and on recent visual activities.

INTRODUCTION

During the past decade, a growing body of research has shown that, with degraded visibility, many people focus and converge for an intermediate distance, which corresponds to their oculomotor resting tonus, even though they may be trying to identify distant targets or to read a near display. These normal variations of oculomotor behavior can seriously impair visual detection, identification, and localization, and they may account for unexplained differences in performances under low visibility conditions among individuals who have ostensibly "good" vision. Two pilots, for example, who both present excellent visual acuity and no refractive error in the examining room, may differ greatly in their ability to detect and identify a distant aircraft in an empty sky. Such differences can arise from anomalous refractive errors, such as empty-field or night "myopia," which result from an involuntary bias of accommodation toward the individual's resting focus. One of the aims of current research is to evaluate the potential benefits of selection criteria or visual aids, such as night glasses, that are based on measurements of the individual's characteristic oculomotor resting state. This research holds the promise of generating new insights into basic processes of oculomotor control and new techniques for predicting and optimizing performances under low visibility conditions.

The purpose of this paper is two-fold: First, I will review some of the early work which led to the view that the resting state of the eyes is an important variable for predicting visual performance. Then, I will summarize two recent studies: (a) individual differences in oculomotor responsiveness, and (b) the effects of near work, which show that these variables may also have an important impact on oculomotor behavior in low visibility conditions. This discussion will concentrate on the resting state of accommodation, which we call the "dark focus," because its characteristics and their implications are better understood than those of the resting state of the vergence system ("dark vergence").

I. The Resting State of the Eyes

Research on the resting state of the eyes has long been a topic of interest to vision scientists. According to classical theorists, the eyes relax at the far point of their operating range (2, 3). This view assumes that active effort is required only to focus from near stimuli, while passive forces, such as the natural elasticity of supporting tissues, are responsible for shifting focus from near to far stimuli. Several authors during the 1940's and 50's challenged this view, proposing instead that the relaxed eye focuses for an intermediate distance and that this intermediate resting focus might account for problems such as "night myopia" which seemed paradoxical from the classical viewpoint (4-8). Their data-base was slim, however, and their novel ideas had little impact on mainstream theory and practice.

During the early 1970's, Leibowitz and Hennessy, at the Pennsylvania State University, developed the laser-Badel optometer, which provided a new impetus for investigating the resting state of accommodation (9). Unlike previous measurement techniques, the laser optometer offered a convenient and accurate means for measuring the eye's focus without stimulating an accommodative response.

One of the first questions we examined with this device was where the eye focuses in total darkness. As illustrated in Fig. 1, measures of the "dark focus" of college students confirmed the intermediate resting state hypothesis, and they showed unexpectedly wide individual differences among subjects who had normal vision (10). The average dark focus measure corresponded to about 1.5 diopters (D) of "myopia," a focal distance of only 67 cm. Individual dark focus values were widely dispersed, with a few subjects resting near optical infinity (0 D) as predicted by classical theory, while others focused to distances as close as 25 cm (-4.0 D).

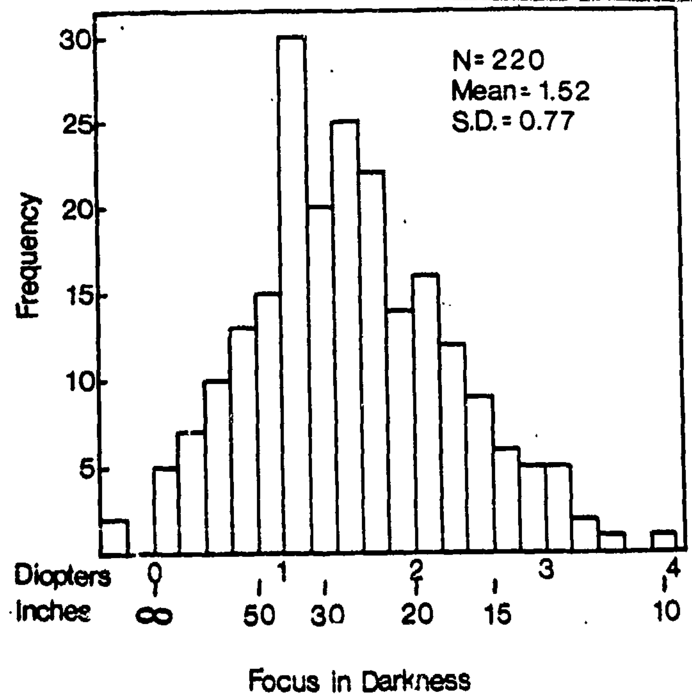

Figure 1. Distribution of dark focus values for 220 college students. All measures were taken with a laser optometer with the subjects normal optical correction in place. (From Leibowitz & Owens, 1978)

II. The Dark Focus and Anomalous Myopias

These findings led us to reopen the question of why anomalous refractive errors, particularly myopia, are often found under degraded visibility conditions. Nearly 200 years ago, the astronomer, Maskelyne reported that he became myopic under low illumination (11). This problem, called "night or twilight myopia," was rediscovered on several occasions and was usually explained as resulting from increased spherical aberration with dilated pupils. Later work, however, showed that anomalous myopia also occurs under conditions where pupillary diameter is normal, such as in a bright empty sky (12) and when using optical instruments (13). This discovery meant that pupil size and ocular aberrations are not key factors.

As noted before, several investigators had proposed that accommodation is responsible for the anomalous myopia. We decided to investigate this hypothesis by comparing dark focus measures of a group of college students with the level of anomalous myopia exhibited by each subject (14). The refractive state of 30 subjects was measured under four conditions, while viewing: (a) total darkness (the dark focus), (b) a distant outdoor scene through a filter that reduced ambient light by a factor of 16,000 (night myopia), (c) a bright texture-free Ganzfeld (empty-field myopia), and (d) a grating in a microscope that had been focused by the subject (instrument myopia). The results are illustrated in Fig. 2 as scatter diagrams comparing individual dark focus values with the same subjects' anomalous myopias. In all conditions, the level of anomalous myopia was highly correlated with the subject's dark focus.

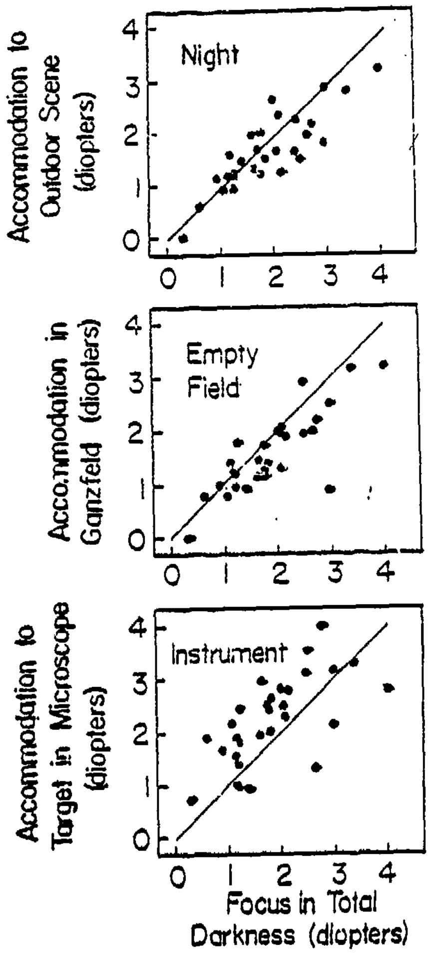

Figure 2. Scatter diagrams comparing the dark focus of 30 subjects with their levels of anomalous "myopia" when viewing (a) a dim outdoor scene, (b) a bright Ganzfeld, and (c) a grating in a microscope. Product-moment correlations between the dark focus and anomalous myopias were 0.84, 0.81, and 0.68, respectively. (From Leibowitz & Owens, 1975)

We interpreted these findings as illustrating a general principle of accommodative behavior. Whenever (1) the stimulus is degraded, or (2) changes in the eye's focus have no appreciable affect on the retinal image, accommodation involuntarily shifts toward the observer's intermediate dark or resting focus. The consequences of this response bias for a hypothetical subject, whose dark focus corresponds to 1.0 D, are illustrated in Fig. 3. Note that as stimulus quality is reduced, accommodative responses are progressively biased toward the individual's dark focus. For strong stimuli, such as a bright acuity chart, focus is fairly accurate, producing a response function with a slope that approaches the ideal value of 1.0. With weaker stimuli, the eyes' focusing range gradually diminishes, producing response functions with progressively shallower slopes, until with very weak stimulus, accommodation remains at the dark focus regardless of stimulus distance, yielding a slope of 0.

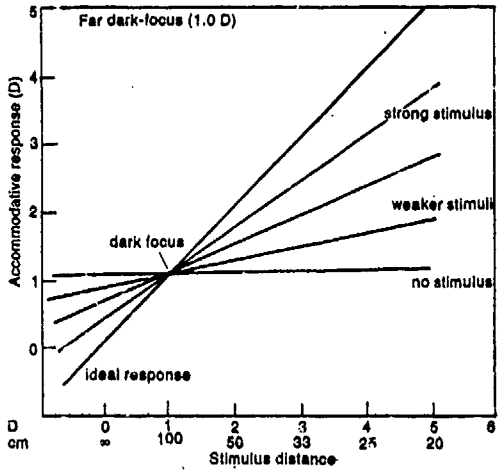

Figure 3. Hypothetical functions illustrating the effects of reduced stimulation on accommodation. As stimulation is degraded, focusing response are progressively biased toward the dark focus, resulting in increasing "myopia" for targets beyond, and increasing "hyperopia" for targets nearer than the distance of the dark focus. Focus is always accurate for objects located at the distance of the dark focus.

Thus, we become functionally "presbyopic" when stimulation is degraded, focusing accurately only for stimuli located at the same distance as our particular dark focus.

III. Focusing Biases with Strong Stimulation

Further work showed that this bias toward the dark focus occurs in a wide variety of conditions, including situations in which the stimulus is not obviously degraded, as with video display terminals (15, 16). One of the more striking examples of such inappropriate accommodation is the "Mandelbaum Effect" (17, 18). This phenomenon, illustrated in Fig. 4, occurs when one is trying to see a distant object through an intervening surface such as a window screen. Many observers report that the screen "captures" their eyes' focus and seriously interferes with visibility of distant stimuli. This phenomenon could be particularly hazardous to pilots who are attempting to see other aircraft or beacons through a dirty or scratched windscreen (19).

We now know that the Mandelbaum Effect occurs because, when confronted with two stimuli superimposed at different distances, the eyes consistently focus the stimulus lying closer the distance of the observer's dark focus (18). This focusing error persists despite strong voluntary effort to ignore the screen and to see the distant object. Incidentally, the easiest way out of this accommodation "trap" is to move the head laterally, thus smearing the image of the screen across the retina while holding that of the distant object on the fovea.

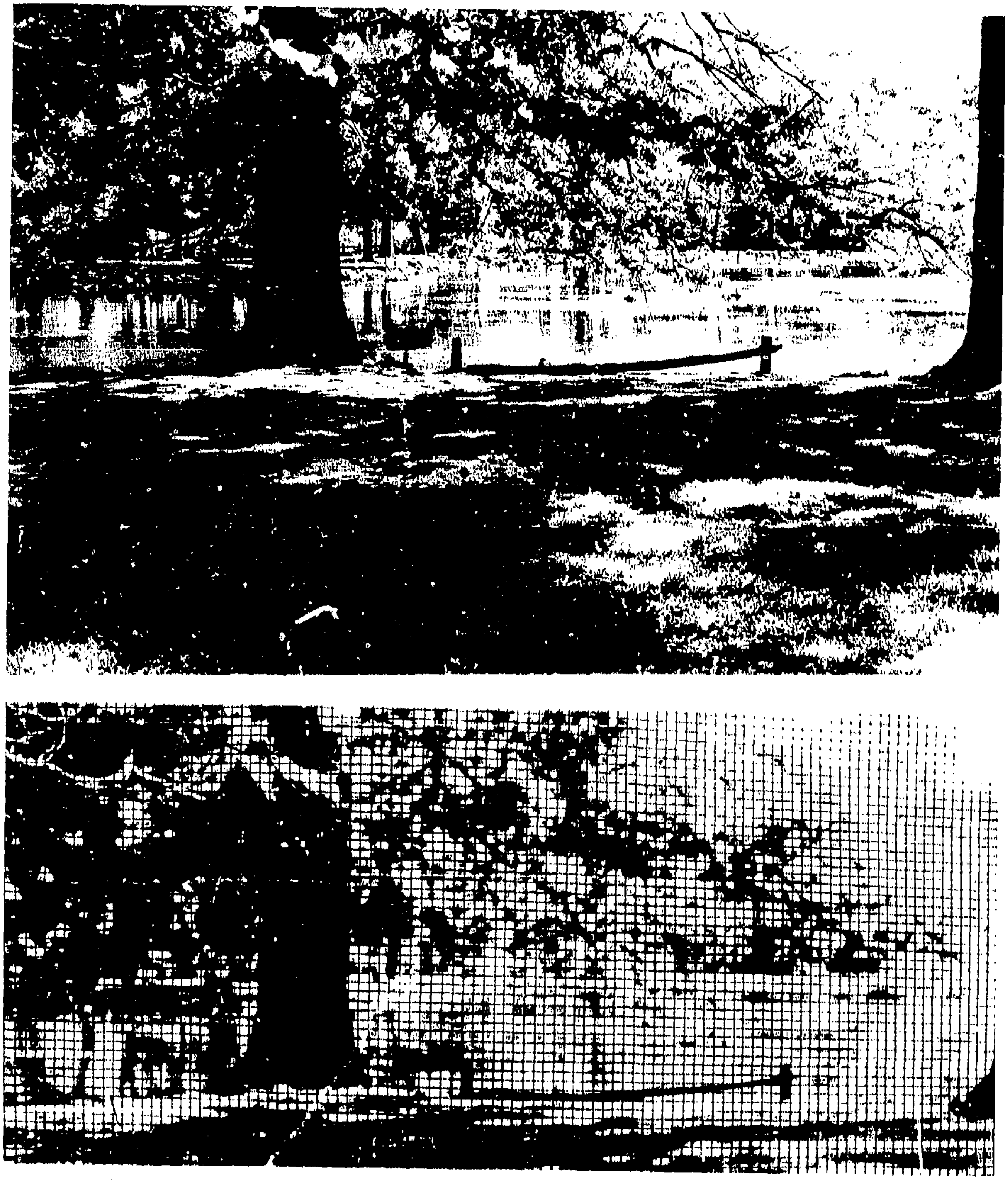

Figure 4. Whenever two images are superimposed on the retina, the eyes tend to focus involuntarily for the object that lies closer to the observer's dark focus distance. This phenomenon, known as the "Mandelbaum Effect," can be especially [illegible] when the intervening surface is a [illegible] windscreen.

IV. Predicting and Correcting Anomalous Refractive Errors

From the human factors standpoint, the most significant implication of this research is that the dark focus can serve as a basis for predicting a person's susceptibility to anomalous refractive errors such as night, empty-field, and instrument "myopia," and the Mandelbaum Effect. The evidence indicates that these anomalous "myopias" are not refractive errors in the usual sense. They are not due to structural characteristics of the eye, but rather, they arise from normal variations in the responsiveness of accommodation. Since the dark focus is not closely correlated with standard clinical measures of refractive status (20), these focusing errors are not predictable on the basis of conventional visual assessment techniques. They might be corrected, however, by simply providing a spectacle prescription based on the individual's dark focus. In effect, this prescription would optically reposition the dark focus so that it matches the distance of the visual task.

At least three studies have attempted to eliminate anomalous myopia with spectacle corrections based on the dark focus. So far, the results are quite encouraging, but as we shall see, more work remains to be done. In general, the visual enhancement resulting from these special prescriptions depends on two factors: (a) the individual's characteristic dark focus, and (b) the quality of available stimulation. Greatest benefits are typically obtained for subjects who have a relatively near dark focus and are working under severely degraded stimulus conditions.

One study evaluated the utility of optical corrections based on dark focus for vision during night driving (21). A preliminary experiment, which measured accommodation for distant targets under simulated night highway conditions, indicated that accommodative response were a compromise between optimal focus (0 D) and the subject's dark focus. It appeared that most subjects focused about half-way (optically) between their particular resting distance and the stimuli of interest. We therefore decided to test the effects on nighttime acuity of three optical corrections: i.e., (a) the subject's normal daytime prescription, (b) a "DF" correction, which placed subject's dark focus at infinity, and (c) a "DF/2" correction, which was the average of the daytime and DF corrections.

The results showed that the DF/2 correction was best, producing acuity enhancements as great as 25% for subjects with an average dark focus value (1.5 D). This finding was confirmed by subjective reports from a field study in which 9 subjects were given three (unlabeled) corrections to try while riding in a car at night. Eight of the subjects selected the DF/2 correction as noticeably better than either the DF or daytime prescriptions, and all 9 subjects reported that the DF correction was noticeably worse. One subject, who had an opportunity to test the glasses over a 90-mile distance which included areas of heavy fog and snow, reported that, although the DF/2 correction was best for clear weather, the DF correction seemed superior in bad weather. This reaction probably resulted from a further shift of his accommodation toward the dark focus as visibility deteriorated.

Two subsequent studies have investigated corrections of empty-field myopia based on the dark focus. In the first (22), we measured detection thresholds for a small point of light superimposed on a bright uniform background, while the subjects wore four different optical corrections: i.e., the same three listed for the previous study plus an additional "overcorrection," which was 1.5 times the power of the DF correction. Again, visual performance was enchanced most for subjects with nearer dark focus values, however, in this case, the DF correction was clearly best for all subjects. When the threshold data were related to nomograms which predict aircraft sighting ranges, we found that the DF correction produced improvements ranging from 26% for a subject whose dark focus was 1.0 D to 316% for one whose dark focus was 2.0 D. While the DF/2 correction was substantially better than the subjects' normal daytime prescription, it was consistently less effective than the DF correction.

These findings were extended in a study by Luria (23) at the Naval Submarine Research Labs at Groton. He measured contrast thresholds for targets ranging in size from 1 to 50 min of arc, with and without optical corrections based on the dark focus. The results showed, as expected, that empty field myopia poses a problem only for detection of relatively small targets (i.e., < 8 min of arc), and corrections based on the observer's dark focus enhanced detection of small targets by differing amounts for different subjects. One with a "far" dark focus (1.0 D) improved by about 10%, while one with a "near" dark focus (4.0 D) improved by almost 600%. It is interesting to note that the two subjects who exhibited the greatest and least improvement were both clinically emmetropic. That is, standard clinical tests indicated that <u>neither</u> subject required corrective lenses.

To summarize, the evidence indicates that anomalous refractive errors are primarily the result of inappropriate accommodation. When stimulation is degraded (as in low illumination, inclement weather, or a bright empty field) and when the eye has the option of "selecting" its focus (as with the Mandelbaum Effect and many optical instruments), accommodation is involuntarily biased toward the observer's dark focus. Since the dark focus distance varies widely among subjects with normal vision, the magnitude of anomalous refractive errors and their impact on visual performance also show great individual differences. At the present, the dark focus appears to offer the best solution for predicting such focusing errors and for providing appropriate optical correction. I want to emphasize that the same dark-focus correction is not appropriate for all low visibility conditions. The quality of visual stimulation must also be taken into account. Since accommodative responsiveness decreases gradually with reduced stimulation (Fig. 2), optimal correction for marginal visiblity conditions, such as night driving, is a compromise between the usual daytime prescription and the full DF correction. In contrast, under severely degraded conditions, such as an empty sky, the full DF correction is optimal.

V. Current Studies of Accommodation

Early in our work on accommodation, it became evident that not all subjects accommodate equally, even though they may have similar dark focus values. We first noticed such individual differences in Johnson's dissertation (24), which showed that the slope of accommodative response functions of some subjects declined faster than that of others as illumination was reduced. Recall that, as shown in Fig. 2, the response function slope is a good index of the overall responsiveness or "gain" of the accommodative system, with higher slopes (approaching the limit of 1.Ø) indicating greater focusing precision. Johnson's data indicated that, as stimulation was degraded, some subjects shifted toward their dark focus more readily than others.

This year, we have followed up on this observation by measuring the accommodative response functions of 69 college students who viewed monocularly a bright, high-contrast matrix of Snellen E's. The stimulus was presented in a Maxwellian-view optical system which allowed variation of optical distance from Ø to 4 D, with no concomitant variation of luminance or visual angle. We also measured the dark focus of each subject as well as their accommodation for the letters at five different optical distances. All subjects wore their normal refractive corrections and were encouraged to focus the letters as clearly as possible.

The results are illustrated in Fig. 5 as frequency distributions of (A) the dark focus, and (B) the accommodative response function slopes. The dark focus data are typical of college freshmen, with a mean of 1.1[illegible] D and a standard deviation of Ø.73 D. In contrast, the accommodative response function slopes were somewhat startling. Only 2 subjects focused accurately, producing slope values greater than Ø.9; the focusing behavior of most was far less precise, with an average slope of only Ø.57. This means that, even with a bright high-contrast target, the accommodation of many subjects was biased toward their resting state. It also means that some subjects are likely to exhibit anomalous refractive errors even with strong (albeit monocular) stimuli. This suggests that "low-slope" people are more susceptible to anomalous myopias and, therefore, may require a dark-focus correction more readily than "high-slope" subjects. I should mention that there is no correlation between the subjects' dark focus values and their response function slopes, so we cannot eliminate the problem by selection on the basis of dark focus.

Further research will be necessary to clarify the basis for these individual differences in accommodative responsiveness and their impact on performance outside the laboratory. One possibility is that some subjects rely more heavily than others on input from binocular vergence to control accommodation (25). If so, their focusing behavior for a monocular stimulus is not representative of real-world performance. Another possibility is that their accommodative system has reduced sensitivity to spatial contrast (26). If so, their focusing deficiencies might be attributable to an oculomotor analogue of amblyopia. In any case, individual differences in accommodative responsiveness may prove to be as important as the dark focus for predicting focusing behavior under operational conditions.

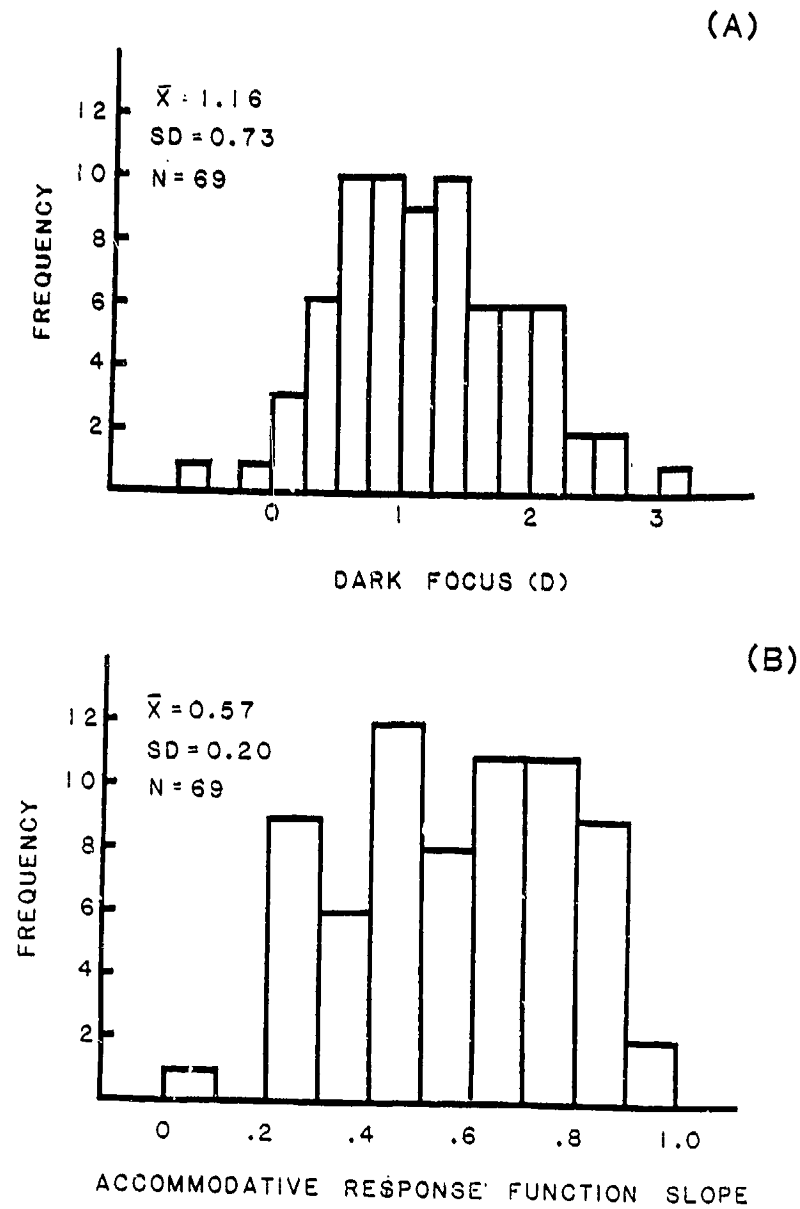

Figure 5. Distributions of (A) dark focus values and (B) accommodative response function slopes for a group of college students. Note that focusing performance, as measured by response function slopes, is quite imprecise for many subjects, even though they were viewing a bright high contrast target.

Another current study investigated the effects of near work on accommodation. There is ample evidence that an individual's dark focus is relatively stable over time periods of up to a year (27-29). Other research, however, indicates that the dark focus can be influenced by a number of situational variables, including emotional arousal (30, 31), anxiety (32), and strenuous visual tasks (33, 34). So far the evidence is somewhat fragmentary. We know little about the generality, longevity, or consequences of these effects, but most would agree that they deserve thorough investigation. One outcome of this research should be determination of the relevance of these effects to real-world applications of the dark focus.

A couple years ago, two of my students, Karen Wolf and Kim Brown, asked if individual differences in the resting state of the eyes might be related to problems of visual fatigue. They reasoned that people who have a "far" resting state must exert more effort at near work than those who have a "near" resting state. Their hypothesis developed into an interesting course project, which Wolf and I later extended.

In one experiment, we tested accommodation and vergence performance before and after subjects read textbook material for one hour (35). Half of the subjects read from the original text, and the other half from a video display terminal (VDT). A head rest was used to maintain viewing distance at 20 cm for both displays. In addition to the oculomotor tests, we asked the subjects to estimate the level of visual fatigue they had experienced on a scale from 1 to 7, where 1 meant none whatsoever and 7 meant extreme fatigue.

The results showed no difference between the VDT and hard copy conditions. Both displays induced significant changes in focusing behavior and in the resting states of accommodation and vergence. Furthermore, the magnitude of these changes depended on the subject's initial resting state. The combined data of all subjects, shown in Fig. 6, exhibited a "myopic" shift of about 0.5 D for both the mean dark focus and the entire accommodative response function.

When the data were broken down according to the subjects' initial resting states, as shown in Fig. 7, we found that subjects who had a "far" dark focus or dark vergence changed significantly more than those who had "near" resting states. The changes in dark vergence and dark focus are not correlated, however, primarily because the subjects initial resting states were not correlated. In fact, the dark focus and dark vergence data of half the subjects are categorized differently in Fig. 7. This apparent dissociation suggests that the dark focus and dark vergence positions are determined by independent mechanisms (36).

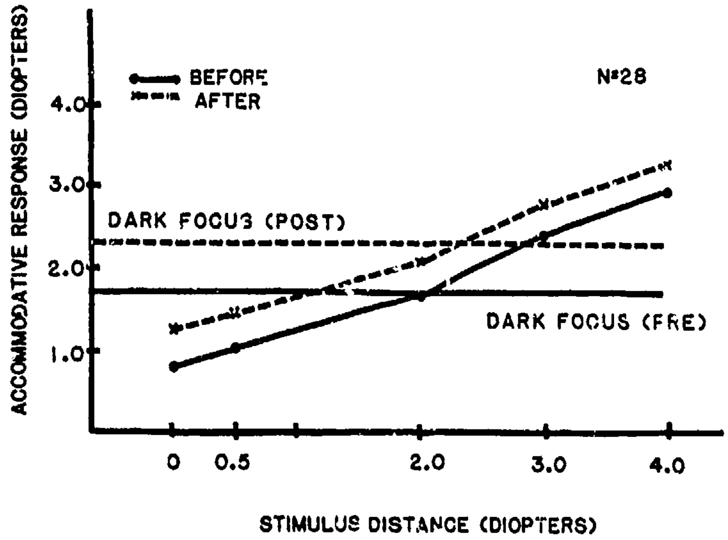

Figure 6. Mean dark focus (horizontal lines) and accommodative response functions before and after subjects read textbook material for one hour at a distance of 20 cm. Note that all measures be-came more "myopic" after reading. (From Owens & Wolf, 1983)

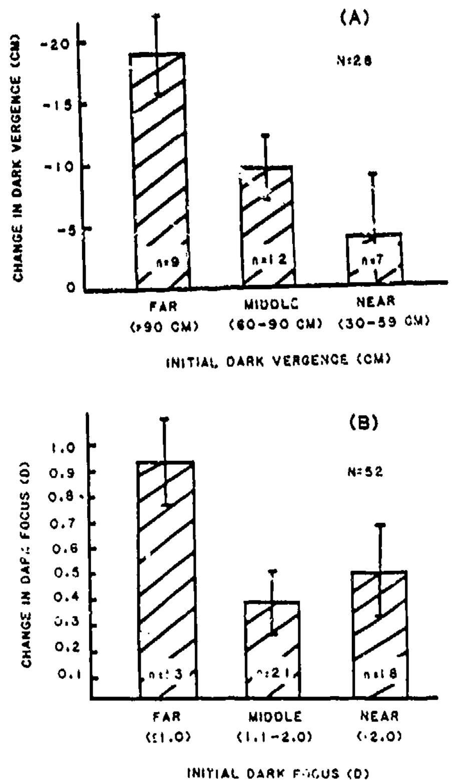

Figure 7. Changes in the (A) dark vergence and (B) dark focus for subjects whose initial resting states corresponded to a "Far" subjects changed significantly more after reading. (From Owens & Wolf, 1983)

The subjective ratings of fatigue also revealed an interesting correlation with the changes in dark focus and dark vergence. The scatter diagrams in Fig. 8 compare individual subjects' fatigue ratings with the magnitude of changes in their (A) vergence and (B) dark focus. Although fatigue ratings were significantly correlated with changes in dark vergence, they were clearly not related to changes in dark focus. This suggests that independent variations of the dark focus and dark vergence may be responsible for different aspects of "visual fatigue". While changes of dark vergence appear to be related to feelings of eye-strain, changes of dark focus may affect acuity and contrast sensitivity without noticeable discomfort.

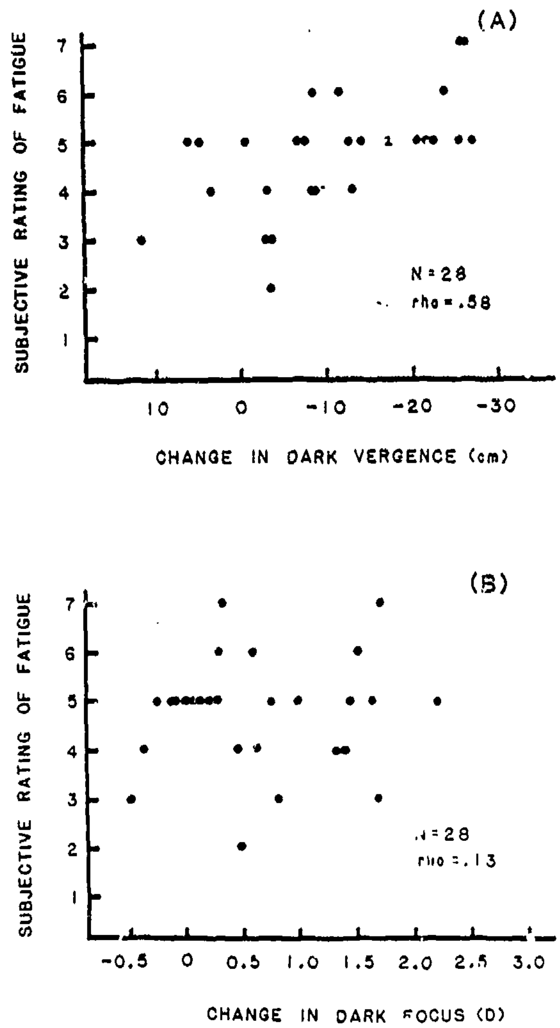

Figure 8. Scatter diagrams illustrating the relation of subjective ratings of visual fatigue with individual's changes in (A) dark vergence and (B) the dark focus. Although subjective fatigue was significantly correlated with changes in vergence, it was not related to changes in accommodation. (From Owens & Wolf, 1983)

We are still a long way from understanding the mechanisms of visual fatigue, but these data indicate that individual differences in the resting states of accommodation and vergence may be key variables. At the same time, they raise new questions about practical applications of the dark focus. It appears, for example, that a person who normally has a far dark focus may exhibit exaggerated anamalous myopias following a relatively brief period of near work. Further research will be necessary to test this possibility, as well as to determine how long such effects might persist, their relation to time spent on the preceding task, and whether changes in dark focus and dark vergence have interactive effects on visual performance.

CONCLUSIONS

Returning now to the theme of this session, performance under low visibility conditions, we have sampled a growing literature which shows that oculomotor performance varies greatly among subjects with normal vision. These individual differences are most pronounced under degraded stimulus conditions, but they are also evident in some high-visibility situations, as with optical instruments, VDTs, and when viewing distant objects through an intervening surface. To a large extent, such anomalous performance can be predicted from the dark focus, which corresponds to the resting or tonus state of accommodation. Thus, the myopias encountered in darkness or a bright empty field can be corrected with spectacles based on the individual's dark focus. Focusing performance under moderately degraded conditions is more difficult to predict, however, because of variations in stimulus quality and individual differences in accommodative responsiveness. In addition, situational variables, such as stress, anxiety, and near work, can affect the resting state of the eyes, which may also have significant visual consequences. Several laboratories are already pursuing many of these questions. As the experiments are completed and the story unfolds, we are likely to move closer still to full optimization of low-visibility performance.

REFERENCES

1. Owens, D. A. 1984. The resting state of the eyes. Am. Sci. 72:378-387.

2. Helmholtz, H. 1909. Physiological Optics, Vol. 1, pp. 136-137. Dover, New York (1962).

3. Maddox, E. E. 1893. The Clinical Use of Prisms, pp. 83-92. John Wright and Sons, Bristol, England.

4. Cogan, D. G. 1937. Accommodation and the autonomic system. Arch. Ophthal. 18:739-766.

5. Luckiesh, M. and F. K. Moss. 1940. Functional adaptation to near vision. J. Exp. Psychol. 26:352-356.

6. Morgan, M. W. 1946. A new theory for the control of accommodation. Am J. Optom. 23:99-110.

7. Otero, J. M. 1951. Influence of the state of accommodation on the visual performance of the human eye. J. Opt. Soc. Am. 41:942-948.

8. Schober, H. A. W. 1954. Uber die Akkommodationsruhelage. Optik 11:282-290.

9. Hennessy, R. T. and H. W. Leibowitz. 1972. Laser optometer incorporating the Badal principle. Beh. Res. Meth. & Instr. 4:237-239.

10. Leibowitz, H. W. and D. A. Owens. 1978. New evidence for the intermediate position of relaxed accommodation. Doc. Ophthal. 46:133-147.

11. Levene, J. R. 1965. Nevil Maskelyne, F.R.S., and the discovery of night myopia. Roy Soc. Lond. Notes and Reports 20:100-108.

12. Whiteside, T. C. D. 1952. Accommodation of the human eye in a bright and empty field. J. Physiol. (Lond.) 118:65.

13. Hennessy, R. T. 1975. Instrument myopia. J. Opt. Soc. Am. 65:1114-1120.

14. Leibowitz, H. W. and D. A. Owens. 1975. Anomalous myopias and the dark focus of accommodation. Sci. 189:646-648.

15. Kintz, R. T. and D. O. Bowker. 1982. Accommmodation response during a prolonged visual search task. Appl. Ergonomics 13:55-59.

16. Murch, G. 1982. How visible is your display? Electro-Opt. Sys. Des. (March):43-49.

17. Mandelbaum, J. 1960. An accommodation phenomenon. A.M.A. Arch. Ophthal. 63:923-926.

18. Owens, D. A. 1979. The Mandelbaum Effect: Evidence for an accommodative bias toward intermediate viewing distances. J. Opt. Soc. Am. 69:646-652.

19. Roscoe, S. N. 1980. <u>Aviation Psychology</u>, Iowa State University Press, Ames, Iowa.

20. Maddock, R. J., M. Millodot, S. Leat, and C. A. Johnson. 1981. Accommodation responses and refractive error. Invest. Ophthal. & Vis. Sci. 20:387-391.

21. Owens, D. A. and H. W. Leibowitz. 1976. Night Myopia: Cause and a possible basis for amelioration. Am. J. Optom. & Physiol. Optics 53:709-717.

22. Post, R. B., R. L. Owens, D. A. Owens, and H. W. Leibowitz. 1979. Correction of empty-field myopia on the basis of the dark focus of accommodation. J. Opt. Soc. Am. 69:89-92.

23. Luria, S. M. 1980. Target size and correction for empty-field myopia. J. Opt. Soc. Am. 70:1153-1154.

24. Johnson, C. A. 1976. Effects of luminance and stimulus distance on accommmodation and visual resolution. J. Opt. Soc. Am. 66:138-142.

25. Fincham, E. F. and J. Walton. 1957. The reciprocal actions of accommodation and convergence. J. Physiol. (London) 137:488-508.

26. Raymond, J. E., I. M. Lindblad, and H. W. Leibowitz. 1984. The effect of contrast on sustained detection. Vis. Res. 24:183-188.

27. Miller, R. J. 1978. Temporal stability of the dark focus of accommodation. Am. J. Optom. & Physiol. Optics 55:447-450.

28. Mershon, D. H. and T. L. Amerson. 1980. Stability of measures of the dark focus of accommodation. Invest. Ophthal. & Vis. Sci. 19:217-221.

29. Owens, R. L. and K. E. Higgins. 1983. Long-term stability of the dark focus of accommodation. Am. J. Optom. & Physiol. Optics 60:32-38.

30. Westheimer, G. 1957. Accommodation measurements in empty visual fields. J. Opt. Soc. Am. 47:714-718.

31. Leibowitz, H. W. 1976. Visual perception and stress. In: G. Borg (Ed.), Physical Work and Effort. Pergamon Press, New York.

32. Miller, R. J. and R. C. LeBeau. 1982. Induced stress, situationally-specific trait anxiety, and dark focus. Psychophysiol. 19:437-443.

33. Ostberg. O. 1980. Accommodation and visual fatigue in display work. In E. Grandjean & E. Vigliani (Eds.). Ergonomic Aspects of Visual Display Terminals. Taylor & Francis, London.

34. Ebenholtz, S. 1983. Accommodative hysteresis: A precursor for induced myopia? Invest. Ophthal. & Vis. Sci. 24:513-515.

35. Owens, D. A. and K. S. Wolf. 1983. Accommodation, binocular vergence, and visual fatigue. Invest. Ophthal. & Vis. Sci. 24:23.

36. Owens, D. A. & H. W. Leibowitz. 1983. Perceptual and motor consequences of tonic vergence. In: C. M. Schor and K. J. Ciuffreda (Eds.), Vergence Eye Movements: Basic and Clinical Aspects, Butterworths, Boston.

LOW LUMINANCE AND SPATIAL ORIENTATION

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SUMMARY

The majority of studies in the literature have been concerned with the ability to appreciate small differences in luminance referred to as focal-recognition vision. While this ability is essential to a large number of visual tasks, it plays a less important role in the contribution of the visual system to spatial orientation and to gaze stability (ambient-orientation vision). Ambient-orientation vision is critical in many real life situations particularly when the observer or the object of interest is in motion. Although there are very few studies of the parameters of ambient-orientation vision, it appears that it is relatively independent of luminance level. The selective degradation of the two modes of vision has important implications for performance prediction. If we are to improve our ability to predict performance, it will be necessary to pay more attention to the role of vision in spatial orientation, not only at low luminance levels, but over the entire functional range of the visual system.

INTRODUCTION

Historically, luminance has been of fundamental interest to visual scientists and, as a consequence, an extensive data base relating visual performance to the quantity of light is available. The curve in Fig. 1 marked "focal-recognition" presents the theoretical relationship proposed by Hecht to describe the dependence of visual acuity on luminance (1). This curve, which was derived from the assumption that the appreciation of small differences in luminance is based on the rate of bleaching of photopigments, accurately describes empirical data on grating, single line, vernier, and stereoscopic acuities, and intensity discrimination. At high luminance levels, luminance differences are not a critical factor in performance. However, as the quantity of light is lowered, any reduction in luminance becomes progressively more important in degrading performance. In addition to providing a test of theory, this function is extremely useful in predicting visual performance. It provides a convenient and succinct quantitative description of the common observation that detail vision is degraded at night and is applicable to a wide variety of performance situations.

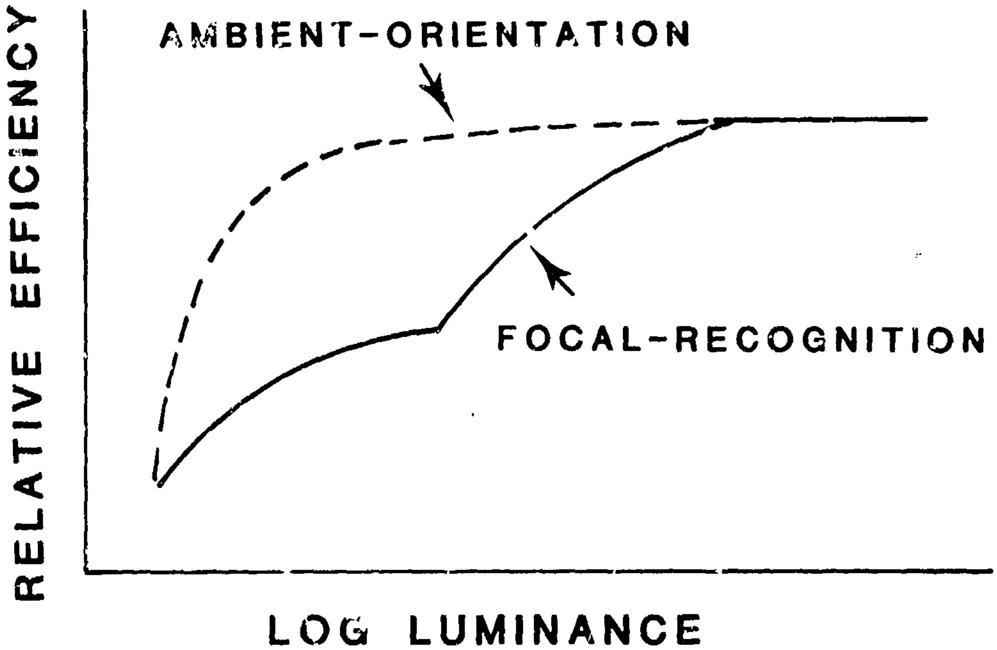

Figure 1. Comparsions of the relative efficiency of the focal-recognition and ambient-orientation systems as a function of luminance. The maximum has been artibrarily equated for the two systems. The focal-recognition curve is based on the theoretical relationship derived by Hecht (See reference 1). The ambient-orientation function is an estimate based on a limited number of observations (See text).

There are, however, serious limitations to the generality of this function for performance prediction. The tasks described by this relationship all involve the appreciation of small luminance differences or fine detail in the foveal retinal image. The appreciation of fine detail is critical in many tasks such as reading, detecting and identifying a target, or discriminating depth binocularly. For such tasks, both luminance and the optical quality of the retinal image are the primary factors determining performance. The limitations of this function derive from the fact that the visual contribution to performance also many tasks which do not depend on the appreciation of small luminance differences (2). In particular, the role of vision in spatial orientation and in gaze stability appear to follow a different functional relationship to luminance. It is the purpose of this paper to describe these functions and to analyze this relationship.

The Two Modes of Processing Visual Information

A convenient way to approach the contribution of vision to performance is in terms of the two modes of processing visual information concept. This framework, which was originally derived from neurological studies of the hamster, posits two different catagories of visual tasks. These are:

(1) A "focal" mode which involves the appreciation of fine detail and object recognition. In general, this mode is concerned with the question of "what?", e.g., reading, identifying individuals or aircraft.

(2) An "ambient" mode which subserves spatial orientation and gaze stability and is generally concerned with the question of "where?", e.g., determination of whether we are stationary or moving, the orientation of our bodies in space and their relation to other objects.

The history and details of this approach have been summarized in several recent articles (3,4). In the present context, it will suffice to point out that the two modes can function independently and that they are sensitive to different stimulus qualities which are critical in performance prediction. To illustrate some of these differences, consider the observation that it is relatively easy to walk and read at the same time. Although one's attention is dominated by the reading material, it is possible simultaneously to locomote and to avoid obstacles. This example illustrates the functional dissociation of the two modes as well as the fact that while the focal mode typically involves awareness, the ambient mode may be carried out reflexively or with minimal awareness.

As noted above, the two modes also differ with respect to the role of luminance. The appreciation of fine detail, which plays a major role in object recognition, is systematically degraded at low luminance levels. However, at luminance levels for which both object recognition and reading are degraded, it is still possible to locomote without difficulty. Consider the walking while reading example. Under luminance levels at which reading is no longer possible, locomotion is unaffected. The differential dependence of focal-recognition and ambient-orientation tasks on luminance has been referred to as the selective degradation of the two modes of processing (5).

Laboratory studies of the relation between spatial orientation and luminance support the view that spatial orientation is less dependent on luminance than spatial orientation. Fig. 2 presents the frequency of detecting a small peripheral stimulus as well as the accuracy with which it can be localized (in terms of polar coordinates) as a function of stimulus energy (6). For the recognition criterion, the function relating frequency of seeing to energy follows the familiar ogive function. However, if the stimulus can be detected, localization accuracy remains constant independent of luminous energy. If the stimulus is visible, even if only on a small percentage of trials, it can be localized. Higher levels of stimulus energy, by increasing either luminance or exposure duration, will improve the frequency of detection but will have no effect on the localization accuracy of visible stimuli.

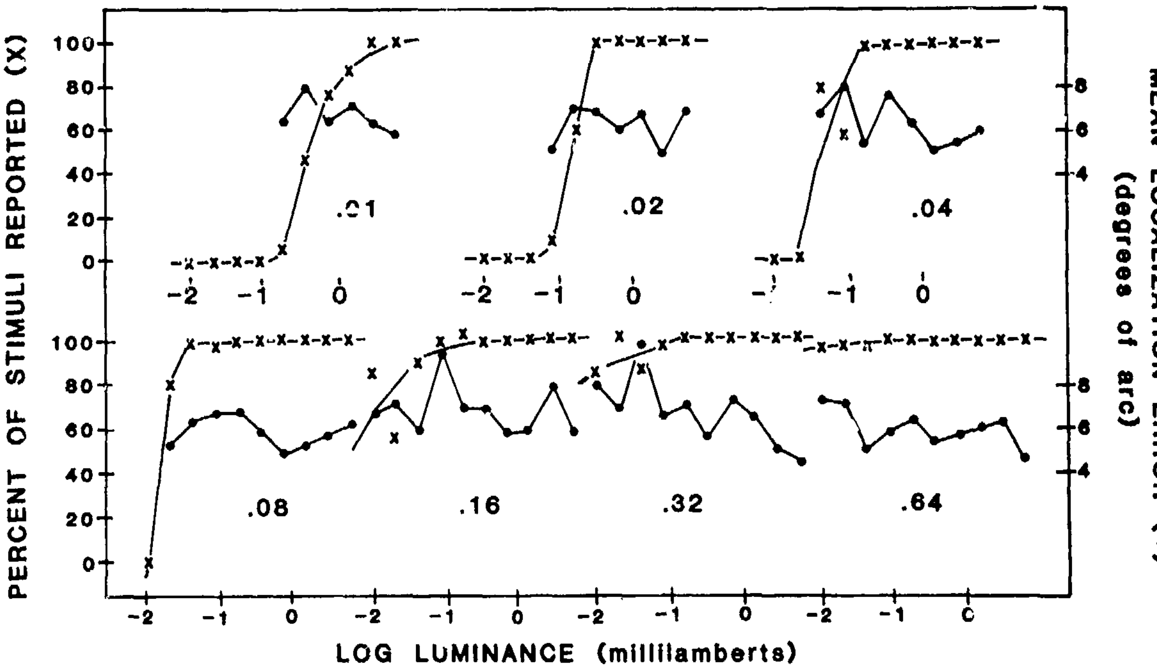

Figure 2. Percentage of stimuli detected and mean radial localization error as a function of luminance for various durations of exposure (6).

Another example of the independence of spatial localization and luminance for suprathreshold stimuli is provided by studies of the phenomenon of illusory self-motion or "vection". If a relatively large area of the visual field is moved, such as when we are sitting in a train or automobile and the vehicle next to us moves, we may feel ourselves moving. At the same time the vehicle which is actually moving appears to be stationary. Vection can be assessed with the aid of a pattern of vertical stripes, affixed to the inside surface of a large drum, which is rotated around the vertical axis of the observer. When the drum is rotated, the subject will at first report stripe motion closely followed by a mixed sensation of stripe-motion and self-motion in the opposite direction. The stripe-motion gradually diminishes and is replaced by self-motion. Within five to ten seconds, stripe-motion ceases, the stripes appear stationary, and the observer experiences a compelling sensation of self-motion (referred to as "saturated" motion). Because the self-motion in this example is with respect to the vertical axis, it is referred to as circular vection (7). We have determined that three parameters of circular vection, time to onset of self-motion, time to complete (saturated) self-motion, and the duration of the motion after-effect are strikingly independent of luminance over most of the functional range of the visual system (8). The results of this study, which also involved severe levels of optical blurring, indicate that when the moving contours are visible, no matter how dim or blurred they may be, full circular vection is experienced. Increases in either luminance or optical quality have no effect on any of the parameters of illusory self-motion.

While it would not be accurate to characterize the visual contribution to spatial orientation as completely independent of luminance or contrast, it appears that for the measures investigated to date, spatial orientation is maintained at luminance levels for which object recognition is degraded. While luminance levels and contrast are critical in determining the level of performance of focal recognition tasks, they are relatively less critical for ambient-orientation tasks. A rough estimate of the functional relation between efficiency and luminance level is proposed in Fig. 1 by the curve marked "ambient-orientation". The ambient curve is based on a small number of studied as compared with the extensive literature summarized by the focal-recognition function. Clearly, additional research will be required to delineate this function as the curve proposed here represents only a best guess based on limited data. Although we know that many ambient functions such as self-motion and gaze stability are relatively insensitive to luminance, it is not clear that this class of responses is optimal at all luminance levels (9,10).

Implications of Selective Degradation

Laboratory studies typically involve a relaxed, unstressed subject performing a single task. In contrast, many real life situations, particularly those of concern to this conference, involve dual if not multiple tasks performed under high levels of both psychological stress. In some cases, both ambient and focal vision are involved. For example, driving an automobile requires both steering (orientation by means of ambient vision) and monitoring of the roadway for hazards such as pedestrians, potholds, or other objects (focal-recognition vision). At night, the ability to recognize objects on the roadway and to respond quickly are severely degraded even with the most advanced automotive headlight systems. Accidents, of course, have multiple causes, but the decrease in the accident rate when the roads are illuminated, either artificially or naturally, argues for the importance of luminance level. In view of this, it is noteworthy that typically drivers do not reduce their speeds at night. A possible interpretation of this paradox is that the driver's self-confidence is derived from the orientation system which is not as dependent on luminance level. Since orientation, in this case steering the vehicle, it a continuous task the driver is provided with information or feedback that she/he is performing satisfactorily. Although the steering function may be as accurate as during daylight, the ability to recognize and respond to hazards is, without the awareness of the driver, severely degraded. As a result of the false sense of confidence provided by the ambient system, the driver is neither aware of nor prepared for the infrequent and unexpected demands on the degraded focal recognition system.

While this example is derived from automobile driving, it is applicable to any situation in which both focal-recognition and ambient vision are involved. The high level of efficiency of the ambient orientation system under low luminance levels can produce an unjustified sense of self-confidence that both the orientation and recognition systems are performing adequately. We are not aware that our focal recognition system is selectively degraded so that our ability to recognize and respond to infrequent and unexpected hazards is severely impaired. In many situations, not confined to driving an automobile, we must rely on both modes of processing visual information which are selectively degraded by reduction of luminance.

Some Limitations of the Present Analysis

An implication of the present analysis is the necessity to consider both focal-recognition and ambient-orientation tasks in relation to visually mediated performance. This suggestion is not limited to low luminance environments. Unfortunately, in comparison with the extensive studies of focal-recognition vision, the literature on ambient-orientation vision is sparse. Parametric psychophysical studies such as those described above are few in number and the significance of many orientation related issues such as individual differences, the role of training and the effects of normal aging have been explored only superficially. In addition, most studies of focal functions require the appreciation of fine detail while ambient studies typically involve coarse patterns of stimulation.

In view of this limited data base, it should be pointed out that the differential effect of lowering luminance on the two modes of processing may not apply to all mechanisms of spatial orientation. The spatial orientation functions described above were carried out in the peripheral visual field which is less affected by variations in luminance. This raises the question as to whether spatial orientation measures which depend on central field stimulation would show a similiar independence. For example, expansion of the optical flow pattern is recognized as a powerful cue to the direction of observer movement (11). Since tne central visual field is more sensitive to both motion and spatial separation, it is probably not justified to assume *a priori* that luminance would not be important. Clearly, basic studies of spatial orientation are needed to complement the literature on focal-recognition vision in the interest of accurately predicting visually mediated performance.

Gaze Stability

As an example of the necessity to consider both modes or processing in performance evaluation, it is instructive to examine the task of dynamic visual acuity. This task involves both modes so that degradation of either will impair performance. Resolution when either the target, the observer, or both are in motion is a critical task in many real world applications particularly in the military. As Sheehy (12) has pointed out, there are at least two factors influencing dynamic visual acuity: image blur resulting from the failure of the eye to track the target accurately, and the cost of attention associated with visual pursuit. It has previously been demonstrated that dynamic visual acuity continues to improve with luminance even beyond levels at which static acuity has reached its limit. It will be important to determine whether the beneficial effect of the additional luminance is associated with tracking accuracy, e.g., by reducing motion-induced blur, or whether it is related to attentive mechanisms. Unfortunately, in spite of the fact that motion of the target, the observer, or both is common outside of the laboratory, the vast majority of studies of focal-recognition vision have been carried out under static conditions.

ACKNOWLEDGMENTS

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REFERENCES

1. Graham, C. H., (Ed.) 1965. Vision and Visual Perception. Wiley.

2. Leibowitz, H., Post, R., and Ginsburg, A. 1980. The role of fine detail in visually controlled behavior. Invest. Ophthalmol. 19:846-848.

3. Leibowitz, H. W. and R. B. Post. 1982. The two modes of processing concept and some implications. In: Organization and Representation in Perception. J. Beck, (Ed.). Erlbaum.

4. Leibowitz, H. W., R. B. Post, Th. Brandt, and J. Dichgans. 1982. Implications of recent developments in dynamic spatial orientation and visual resolution for vehicle guidance. In: Tutorials on Motion Perception. Wertheim, A., Wagenaar, W., and Leibowitz, H. (Eds.). Plenum.

5. Leibowitz, H. W., and D. A. Owens. 1977. Science 197:422-423.

6. Leibowtiz, H. W., N. A. Myers, and D. A. Grant. 1955. Radial Localization of a single stimulus as a function of luminance and duration of exposure. J. Opt. Soc. Amer. 45:76-78.

7. Dichgans, J. and Th. Brandt. 1978. Visual-vestibular Interaction: Effects on self-motion and postural control. In: Handbook of Sensory Physiology, Vol. VIII. Held, R., Leibowitz, H. W., and H. L. Teuber, (Eds.), Springer.

8. Leibowitz, H. W., C. Shupert-Rodemer, and J. Dichgans. 1979. The independence of dynamic spatial orientation from luminance and refractive error. Perception and Psychophys., 28:75-79.

9. Post, R. B. 1982. Stimulus control of circular vection and optokinetic after nystagmus. Ph.D. Dissertation, Pennsylavania State University.

10. Shupert, C. L. 1985. The effect of spatial frequency and field size on visual spatial orientation. Ph.D. Dissertation, Pennsylvania State University.

11. Regan, D. 1984. Visual Factors in Flying Performance. Presented at the Tri-Service tAeromedical Research Panel Fall Technical Meeting, Pensacola, Florida.

12. Sheehy, J. B. 1984. Study of Dynamic Resolution. Presented at the Tri-Service Aeromedical Research Panel Fall Technical Meeting, Pensacola, Florida.

Influence of Oculomotor Factors on Space Perception in Reduced Environments

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SUMMARY

This paper discusses three aspects of the relation between oculomotor function and space perception. First, several examples of perceptual attributes mediated by information from oculomotor systems are given. Second, elements of an adaptive oculomotor control system are presented, and finally, several implications of the analysis of opto-ocular motor systems for aircrew performance will be drawn with emphasis on spatial illusions and disorientation.

I. Perceptual Correlates of Oculomotor Systems.

Fig. 1 represents three aspects of space perception: distance, lateral orientation, and elevation.

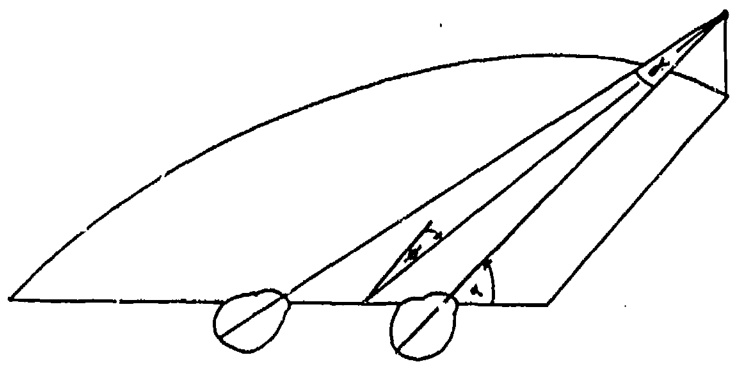

Figure 1. A system of angular egocentric coordinates encoding distance (γ), and lateral (ϕ) and vertical (α) position in the visual field. These are represented as discrete values in the vergence and the horizontal and vertical version systems respectively (19).

These are encoded by the convergence angle (γ) of the disjunctive eye movement system, and by angles α and φ representing the departure of the conjugate eye movement system from a straight ahead reference level. Three parameters thus form the basis for a three-dimensional polar coordinate system centered about the head, with the capability of faithfully signaling the egocentric orientation of a point target in near space. For extended surfaces, however, there is yet an additional spatial attribute to be considered, namely target orientation relative to the frontal plane of the observer. Frontal plane orientation has long been thought to be a matter of stereopsis and binocular disparity (1), but, as Fig. 2 shows, frontal plane orientation about a vertical axis is heavily dependent upon the registration of lateral gaze direction and by analogy, apparent orientation about a horizontal axis is determined by registration of ocular elevation. If convergence and retinal disparity of a line target are held constant by sliding the target along the locus of a Vieth-Muller circle, shown in Fig. 2, or if through any other means the retinal projection of the target is fixed while the apparent lateral orientation is altered, there will occur a corresponding shift in apparent frontal plane orientation (2,3).

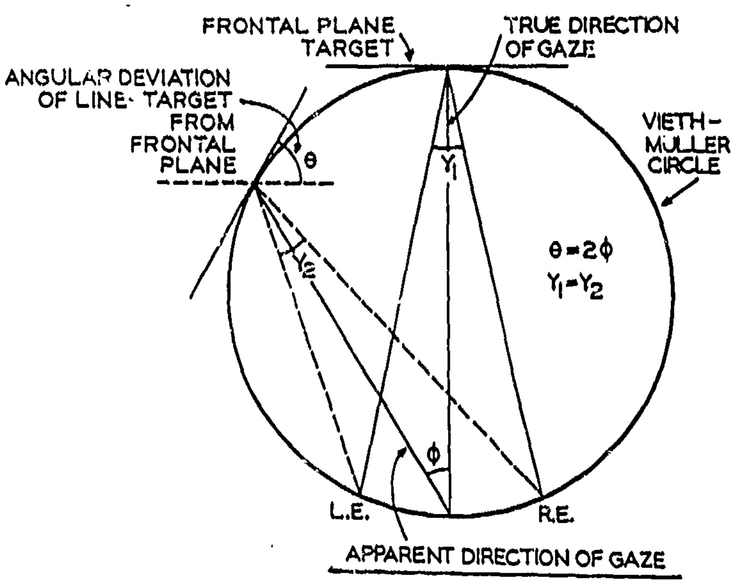

Figure 2. Change in apparent frontal plane orientation (ϕ) with change in lateral orientation angle (ϕ) under constant convergence, image size, and retinal disparity (3).

This relationship between lateral and frontal plane orientation probably underlies the errors in judgment of egocentric target orientation brought about by changes in the gravitational force vector. In this task, upright subjects observed a thin luminous line-target (28.2 cm x .3 cm) of about .01 cd m^{-2} at a distance of 51 cm. The line was pointed toward or away from them at various target pitch angles as shown in the upper panel of Fig. 3. After a 30 sec inspection period, subjects were tilted backward to one of four body pitches where they were required to duplicate the egocentric angle of the line target. Overall, the parallel target (0^{o}) and those oriented top toward the observer had to be rotated yet further toward the subject, while top away targets required additional top away adjustment. These systematic errors in target orientation, shown in Fig. 3, were sinusoidally related to the target inclination and were amplified by increases in body pitch angle (4). Since eye level is reflexively depressed with backward body pitch, in accordance with the Doll Reflex (5), target viewing is accompanied by an apparent target elevation. Although further research is required, it appears likely that illusory target elevation plays a role in selectively biasing the perception of egocentric target orientation.

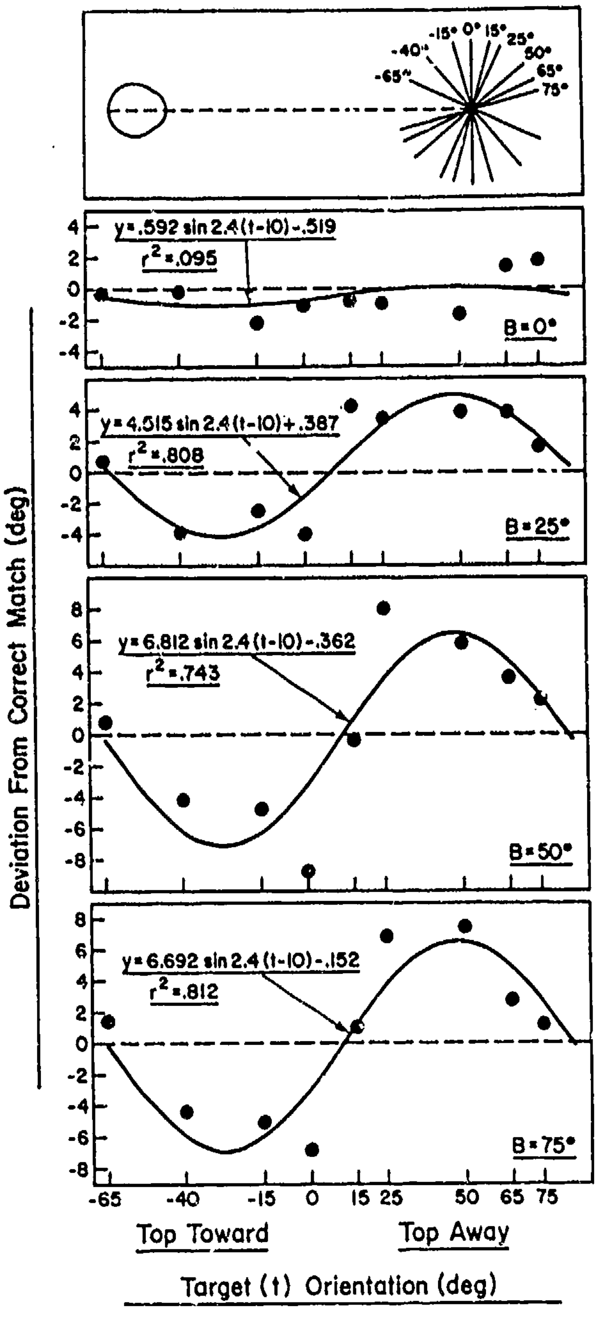

Figure 3. Deviation from correct egocentric match as function of nine target-pitch angles (t) at four degrees of backward body pitch (B). Solid line represents the best fit sine function.

Yet additional spatial attributes, such as apparent size and relative depth, are derivatives of the registration of distance information since retinal angle and retinal disparity are in themselves ambiguous (6,7). Furthermore, kinetic spatial attributes expressing the rate of change in the oculomotor parameters described above also are potential candidates for additional oculomotor-mediated sources of spatial information. The perception of the movement path of a target based on the pursuit system is one example, but additional research is needed to determine the fidelity by which oculomotor systems encode the kinetic dimensions of targets.

II. Adaptive Oculomotor Control Systems

Many, if not all, oculomotor systems exhibit adaptive plasticity in response to sustained asymmetrical postures where, in the absence of further stimulation, there results a persistent change in one or more system parameters. Systems investigated that exhibit adaptation include the saccadic system (8), accommodative vergence (9), disparity vergence (10), lateral version (11), vertical divergence (12), vertical version (13), vestibular ocular response (VOR) gain (14), VOR direction (15), and the resting level (dark focus) of accommodation (16). Although not all of these systems have been modeled, many appear to be characterized by the presence of both fast and slow controllers having short and long time-constants respectively similar to those found in the case of the convergence and accommodation feedback systems (17,10). In order to emphasize the functional significance of these controllers in producing adaptive plasticity and because of the significant role of the vestibular system in spatial orientation and disorientation, a block diagram of the flow of information controlling the VOR is presented in Fig. 4.

Since the vestibular control of eye movements has no feedback channel of its own, the parameters of the gain and orientation element are updated by the optokinetic (OK) and foveal pursuit systems. This insures that the gain in the VOR will be appropriate to nullify the velocity of retinal images consequent upon a head movement, thereby producing gaze stabilization. Adaptive plasticity is assumed to arise from the slow controllers (C) of each system represented as pursuit afternystagmus (PAN) and optokinetic afternystagmus (OKAN), respectively; the slow controller for the VOR being represented in the gain and orientation element. Fast controllers, by contrast, are assumed to govern the transient responses of the system in response to negative feedback. The relation between the two types of controllers is a functional one in that to the extent to which the slow controller is adaptive, in that it is capable of reducing system error, there is less work to be done by the fast controller via the negative feedback loop. On the other hand, the more frequently the error-correcting signals occur, the greater the likelihood that the slow controller will modify its parameters so as to "anticipate" potential future errors. Thus, the negative feedback error-correcting loop is necessary for adaptation to occur, while the adapting (feed-forward) elements reduce the occurrence of subsequent error and eventually bring the system to stable steady state levels.

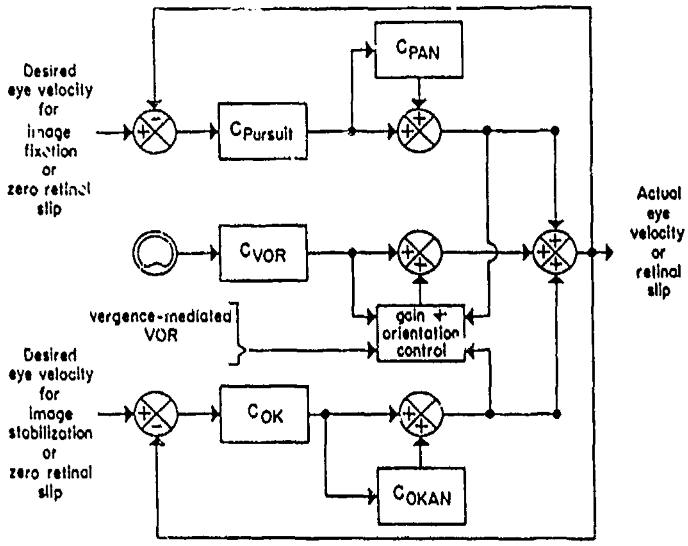

Figure 4. Adaptive control system for the vestibular ocular response (VOR), pursuit, and optokinetic (OK) systems. Slow controllers (C) are represented as the source of adaptive control and the basis for pursuit after-nystagmus (PAN), change in gain and orientation of the VOR, and optokinetic after-nystagmus (OKAN).

III. Implication of Adaptive Systems for Aircrew Performance

The systems described respond to visual stimulation that is both of an optokinetic and optostatic nature. For example, vergence is triggered by binocular disparity, accommodation by target contrast and spatial frequency, version by the foveal fixation reflex, while ocular pursuit systems respond to differences between image and eye velocity. These opto-ocular motor systems encode a large set of perceptual attributes. Consequently, changes in their parameters must inevitably be manifest as changes in perception. In general, spatial illusions will result during the initial adaptation period and again when the conditions that prompted adaptation are no longer present and the system must re-adapt its parameters to the prevailing conditions. In these states, a frequently encountered source of illusion is the need to issue compensatory innervation to the extraocular muscles to maintain fixation on the selected target. For example, changes in the gravito-inertial force vector that stimulate the semicircular canals will also produce nystagmus, the slow phase of which, the VOR, normally is used to produce gaze stabilization. If, however, nystagmus is produced by factors other than head movements in a normal force field, the VOR will operate as a vector pulling the eyes off target. Compensatory innervation frequently will be successful in maintaining fixation by balancing the VOR vector, but will be read out by the system as pursuit movement in the direction or the compensatory signal. For this same reason, a stationary target fixated during ear canal irrigation will appear to be in motion. Illusions cease when the parameters of the newly adapted oculomotor system are sufficient to maintain the eyes on target without the need for additional error-correcting compensatory innervation.

The principle that relates illusion to compensatory ocular innervation is, of course, especially relevant in environments with continually changing gravito-inertial force vectors. The same environments also are conducive of disorientation and motion sickness and for reasons that are similar to those responsible for spatial illusions. Research on perceptual and oculomotor adaptations to displaced, tilted, and reversed visual fields has shown that the conditions productive of adaptation are identical to those that produce the motion sickness syndrome (mss) including lightheadedness, dizziness, drowsiness, nausea, and a number of aesthenopic symptoms (18). In system terms, it appears that the critical feature underlying these symptoms is the presence of recurrent error signals cycling over negative feedback loops for extended periods of time, with some trade off, prior to the onset of symptoms, between exposure time and error magnitude. If the opto-ocular systems adapt their parameters so as to reduce the load on the negative feedback loop, disorientation, and aesthenopia will be unlikely events whereas if an adaptive response is made unlikely or requires an extended time interval, then the manifestations of mss will become highly probable. Further research is needed to determine the conditions that maximize the adaptive response while minimizing the period of exposure to recurrent error signals.

ACKNOWLEDGMENTS

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REFERENCES

1. Ogle, K. N. 1964. Binocular Vision. Hefner Publishing Co., New York.

2. Ebenholtz, S. M. and Paap, K. R. 1973. The constancy of object orientation: Compensation for ocular rotation. Perc. Psychophysics. 74:458-470.

3. Ebenholtz, S. M. and Paap, K. R. 1976. Further evidence for an orientation constancy based upon registration of ocular position. Psychol. Res. 38:395-409.

4. Paap, K. R. 1971. Perception of the egocentric orientation of a line with body tilt in the sagittal plane. M.S. Thesis, University of Wisconsin, Madison, WI.

5. Ebenholtz, S. M. and Shebilske, W. L. 1975. The doll reflex: Ocular counterrolling with head-body tilt in the median plane. Vis. Res. 15:713-717.

6. Wallach, H. and Zuckerman, C. 1963. The constancy of stereoscopic depth. Am. J. Psychol. 76:404-412.

7. Libowitz, H. and Moore, D. 1966. Role of changes in accommodation and convergence in the perception of size. J. Opt. Soc. Am. 56:1120-1123.

8. Robinson, D. A. and Optican, L. M. 1981. Adaptive plasticity in the oculomotor system. In: H. Flohr & W. Precht (Eds.), Lesion-induced neuronal plasticity in sensorimotor systems. Springer-Verlag, New York.

9. Judge, S. J. and Miles, F. A. Short term modification of stimulus AC/A induced by spectacles which alter effective interocular separation. Proceed. Assoc. Res. Vis. and Ophthal. Abs.:79.

10. Ebenholtz, S. M. and Fisher, S. K. 1982. Distance adaptation depends upon plasticity in the oculomotor control system. Perc. Psychophysics 31:551-560.

11. Park, J. N. 1969. Displacement of apparent straight-ahead as an aftereffect of deviation of the eyes from normal position. Percept. Mot. Skills 28:591-597.

12. Ebenholtz, S. M. 1978. Aftereffects of sustained vertical divergence: induced vertical phoria and illusory target height. Perception 7:305-314.

13. Shebilske, W. L. and Karmiohl, C. M. 1978. Illusory visual direction during and after backward head tilts. Percep. Psychophysics 24:543-545.

14. Melvill Jones, G. 1977. Plasticity in the adult vestibulo-ocular reflex arc. Phil. Trans. Royal Soc. of London, B 278:319-334.

15. Callan, J. W. and Ebenholtz, S. M. 1982. Directional changes in the vestibular ocular response as a result of adaptation to optical tilt. Vis. Res. 22:37-42.

16. Ebenholtz, S. M. 1983. Accommodative hysteresis: A precursor for in induced myopia? Invest. Ophthalmol. 24:513-515.

17. Schor, C. M. 1979. The influuence of rapid prism adaptation upon fixation disparity. Vis. Res. 19:757-765.

18. Ebenholtz, S. M. 1984. Dysfunction and plasticity in oculomotor control systems. Proc. Nat. Res. Coun. Human Factors Committee Workshop on Simulator Sickness, National Academy Press, Washington, DC.

19. Ebenholtz, S. M. 1984. Perceptual coding and adaptations of the oculomotor systems. In: L. Spillmann and B.R. Wooten (Eds.). Sensory Experience, Adaptation, and Perception. Lawrence Erlbaum Associations, Hillsdale, NJ.

DISCUSSION

DR. PITTS: For Dr. Owens: One of the things that bothers me about the dark focus measurements is the ignoring of data that was derived out of research at Wright-Patterson Air Force Base, essentially the same data that has been reported time and time again with dark focus. Of course, it was called empty field or space myopia at that time, since it was related to the space program; they are one and the same thing.

They found accommodation postured at about 1 to 1.5 diopters, but the thing that bothers me is that they also found that accommodation postured at this level and after an indeterminate amount of time (the reason why I say it is an indeterminate amount is because it varied between subjects and varied within the same subjects at various times). You would find swings, large swings of accommodation up to 3.5 diopters, usually around 1.5 diopters, but as much as 3.5 diopters. You could not predict it. There was no way to predict it and I am reminded that there are other visual phenomena that follow this pattern; for an example, the autokinetic phenomenon. Anyone who has flown formation at night knows that if you maintain a steady fixation of the eye over some period of time, the lights of the fellow next to you are going to move. There isn't anything you can do about it. You can't predict the distance they are going to move or the direction they are going to move.

Now, we also know there are certain ways we can reduce that sort of thing. The point that I am trying to make is that the changes in accommodation and these posturings that take place are part of the physiological system; and yet the dark focus measured with the specular pattern of the laser system, the Laser-Badal Optometer does not show this. The measurements made in the earlier studies were made with an infrared optometer system. Could you comment on that?

DR. OWENS: First of all, you mentioned data from Wright-Patterson AFB. You are right, I have ignored those throughout. This is the first I have heard of those and I would like very much to see them; however, I am sure those aren't the first data either. In fact, there is data from Whiteside in the early fifties, data from Morgan in the forties, and data from the thirties.

I think the new insight that came through experiments with the laser optometer, and later other devices, was that there are wide individual differences in the dark focus that are not predicted by standard clinical refraction nor any other measure that I know of. I don't think those differences were recognized earlier.

DR. PITTS: It is the variation that you have not found with the optometer that bothers me.

DR. OWENS: That is the second question, right?

DR. PITTS: Well, they are one and the same because if...

DR. OWENS: No, no. They are not one and the same. I would argue that the individual differences that you have seen in our distributions and others are stable over time. In fact, there have been studies that have retested people over time periods of up to a year showing quite high reliability. So, by and large, I would argue that is stable.

DR. PITTS: Yes, but I question that it is only stable when they use the speckle system. Every study that you are talking about is using the laser speckle optometer system and I am wondering if the speckle itself is not acting as a stimulus to accommodation because it doesn't take a lot to lock accommodation in. It only takes one or two targets in empty field space, because that was done by Whiteside in 1955 and '56. In other words, what I am really saying is the stability for an individual bothers me somewhat, knowing that there are other physiological properties of the human body which do not demonstrate those things under the same types of conditions.

DR. OWENS: Let me say this; the data on the stability are not restricted to the laser optometer. Certainly that has been the most frequent instrument, but the same data are obtained with polarized vernier optometers and with retinoscopy done in the dark. I have done a study with Dr. Chris Johnson using his high speed infrared optometer, and comparing those measures with measurements taken with the dark focus. I would like to tell you a little bit about those.

First, I want to agree completely that the laser optometer cannot pick up dynamic drifts of accommodation, nor can any other instrument that is sampling in a very narrow time frame as the laser does. We have found that subjects will produce successive readings that fluctuate. That is, some subjects. I don't understand the basis for these fluctuations. I have found that they are most striking when the subjects are looking at a fully visible field which is not an accommodative stimulus, particularly an isoluminant field where there are red and green, or orange and blue - pick any pair of colors - defining separate areas; but they are of equivalent luminance, thus providing no brightness contrast and apparently not stimulating accommodation effectively. Under these conditions one will hold a stable focus for minutes at a time and then drift over wide excursions, which may be three or four diopters. I don't understand that.

DR. PITTS: That is precisely what I was reporting. Is this true with the infrared optometer, too?

DR. OWENS: Both. That is correct. Furthermore, I think that we have to keep in mind the question. I think the question you are really raising is one of constructive validity, and I think that if the measurements of dark focus were nothing more than an artifact of the measurement system, we would have no hope of predicting and improving an individual's performance, either in an empty field or in the dark. The truth is, we do explain quite a bit of the myopia that subjects exhibit under those conditions. So, I think we have predictive validity there. We certainly are not catching the kinds of drifts and fluctuations that you mentioned.

DR. ADAMS: I want to make a comment, and follow it with a suggestion/question. I think the dark focus is incredibly important for us to study and to take note of, and I think the telling point is that you can, in fact, correct it and get improvement in performance. That can't be simply a measurement error; that is, an instrument-induced error. However, having said that, I want to suggest something radical, which I raised briefly with Dr. Owens earlier. I think it is quite possible that the laser optometer measurement of night myopia or dark focus does, in fact, induce accommodation, and that, in fact, what you are dealing with in that measurement is a combination of night myopia (the real thing) plus proximal accommodation, which clinicians 50 years ago used to talk about, take care of and try to factor out. Proximal accommodation, or awareness, or nearness accommodation is quite real and it presumably has something to do with the subject's or patient's concept of where the object is in space.

Now, that is hard to measure and I don't have any real brilliant ideas about how to do it, though the literature might be helpful. If you accept my proposal that night myopia plus proximal accommodation is involved in the Badal Optometer's measure of night myopia, you might be able to tease out some of the more unusual results you [Dr. Owens] presented toward the end of your talk.

What I am proposing is that even with the Badal system, although the speckle pattern does not seem to stimulate accommodation (and you and your colleagues have shown that very nicely), you know that the drum is within arm's length. You may not accommodate for the first flash, because it is presented short enough that accommodation can't respond that quickly, but now you know it is there; in the second and the third and the fourth flash you will already be in this proximal accommodative state.

Where does that lead in terms of your last comments? I think it is quite possible that night myopia (the real night myopia) probably correlates very well with anticipated correction; that is, how well somebody will perform with the right correction for night myopia. Maybe it is at 0.75 diopters or thereabouts of that total measurement that you have been making, which is about 1.50 diopters. Maybe the lack of correlation that you are finding more recently between the night myopia and the amount that you need to correct it is because you have got that contamination factor in there, which perhaps isn't correlated to night myopia. So, you have got 1.5 diopters of which some fraction, you don't know how much, is proximal accommodation. If you could subtract that out in your studies, so that you were measuring what I would claim is the real night myopia, you might get very nice relationships. I would speculate and predict that there might be a very tight relationship between how much correction you need (functionally) to operate and what the real night myopia is, as opposed to the dark focus.

DR. OWENS: Thank you, Tony. I think that it is a point well taken that the laser optometer is not the ideal instrument to go into the field and use for a number of reasons, and this is one. It can induce unusual response strategies or biases on the part of the subjects, but only some subjects.

Let me just briefly describe some data that I mentioned briefly a few moments ago that I had an opportunity to collect with Drs. Johnson and Post at the University of California-Davis. They have a high speed infrared optometer. We measured accommodation continuously for a group of high school students under four different conditions. One was just sitting in the dark looking into IR-optometer. The subject always had the same posture and the same instrumentation in front of him sitting in the dark.

In another time-frame, we presented the laser speckle pattern reflected from the rotating drum. They were told that they would see red speckles occasionally, but not to pay any particular attention to them and to just sit there and relax. In the third time block, they were seeing the speckles but were supposed to tell us whether the speckles appeared to be moving upward or downward, which is a typical task for the laser optometer measurements.

In the fourth time block, they were sitting in the dark again, no laser speckles, no visual judgments, but rather they were counting backwards by sevens, a difficult cognitive task.

I was surprised by the results. There were no effects of the laser pattern per se; that is, when it was simply flashed with no task instructions; but when the subjects were instructed to judge the motion of speckles within the pattern, we found some of the subjects did show a myopia shift of accommodation. We did not find effects like that from the backward counting task, so one possibility that has occurred to us (we don't have much confidence in it yet, but it is a working hypothesis) is that for some subjects, whatever visual effort is involved in looking for something (trying to make a visual judgment) induces in them an accommodative change which would contaminate a pure dark focus measure.

Now, whether that is due to accommodation or due to a vergence change or a change in autonomic arousal, I really haven't the foggiest notion. But, I am convinced that for some subjects, the laser optometer, and perhaps any subjective optometer of that sort, can induce an unusual measurement.

DR. ADAMS: I just want to ask one thing. Have you ever done the experiment where you look out the window and the person just simply does not know that there is an apparatus with a rotating drum on it that is 14 inches away from their head? It seems to me that if you could do that experiment you could get at the issue that I am raising. I am not surprised at all by the result. I think in fact, that it is very promising in the sense that you could take those individuals who do that, subtract that out, and see what is left.

DR. OWENS: We have not had them look out the window without knowledge of the instrument presence. We have had a couple of set-ups in which they were looking through an interior window into a visual alley, for example, where they couldn't see the optometer located behind the wall. I don't think that made much difference. I want to re-emphasize the point that in the study I did with Drs. Johnson and Post, the subjects were fully aware of the apparatus. The myopic shift that we found was specific to the task in which a visual judgment was required.

COL McNAUGHTON: I just have a general question for anybody that can answer it, maybe one of the pilots or one of the psychologists here. Has anyone ever done a study to see whether your performance in driving during daytime or nighttime, or landing an aircraft, or doing some kind of aviation task during day or night is related to your visual acuity correction? In other words, have we taken someone's glasses off (say you take a real McGoo, with 20/400 acuity with the glasses off) to see what their landing performance is? I have a theory that landing an aircraft is done with ambient vision, so it really should not be particularly affected by taking your glasses off (unless you are making a carrier landing) any more that taking your glasses off affects your ability to drive in either light or degraded visual conditions. That is strictly a focal mode process where you are lining up lights, and is similar to an Atari game, until the last second or so when you start seeing where the carrier comes into view. That is kind of a video parlor type situation with a lot of anxiety built into it. My impression of landing an aircraft is that it is merely done with the ambient cues; motion cues and peripheral cues, and I just wonder if anybody had actually done a study to really look at that.

DR. LEIBOWITZ: I don't know about aviation, but there is a study by John Merritt on the driving simulator where he severely degraded the driving simulator, and there was no effect on the driving performance. So that would fit in with your supposition. I don't know about any aviation studies.

DR. MONACO: I would like to thank you. This finishes the session for today, and we will look forward to seeing you tomorrow.

III. SELECTION/RETENTION/CLASSIFICATION

SEEING IN THE AIR TO AIR ARENA

Jerome B. Hodge, Commander, USN
VF-43
Naval Air Station, Oceana, Virginia 23460

Good morning.

Many of you may not know what these are [showing audience pointer with gloves on ends]. These are hands. Most people associated with Naval Aviation and fighter pilots in particular, will tell you that fighter pilots cannot talk without using them.

After looking at the list of attendees and the participants and noting the subject of their presentations, I was concerned about what I should talk about. As a matter of fact, the average fighter pilot, myself included, doesn't understand many of the technical aspects of how the eye works. However, many researchers, may not know what is required of the fighter pilot. So I will present a fighter pilots perspective of vision research and testing, as it relates to air combat maneuvering and the value of experience.

An interesting aspect of naval aviation, as it relates to vision research, is that each fully encompasses the other. I noticed while looking through the list of subjects to be presented that many factors are covered. We talk about contrast sensitivity, dark focus, accommodative flexibility, and depth perception. We talk about haze and glare and low luminance and spatial orientation and visual acuity. Many of these factors are encountered and dealt with by the fighter pilot on a typical air combat maneuvering flight.

There are, however, limitations as to the breadth of visual factors since air combat maneuvering is basically a day, visual evolution. It proceeds by a certain set of rules. Just as the fighter pilots of World War One had their rules, so does the modern fighter pilot. Visual target identification is a requirement in almost all dogfight situations. Therefore, seeing the target before the target sees you is obviously an advantage. What can we do to enhance an early identification? Training, as it relates to search techniques, is one method. Research to determine how the eye works and the effective aspects of vision in relation to target detection is another. The development of mechanisms to aid visual acuity is yet another.

What then are some of the factors experienced by the fighter pilot during his flight? The day may be overcast, the sun totally obscured by clouds. It might be a bright, clear day. It might be a hazy day with the haze layer only extending up to a certain altitude, then clear above that. In the haze the pilot may be able to see a certain size target only a short distance, while in the clear sky above the haze, he would be able to see the same target for several miles. The brightness of the sun causes varying degrees of glare depending upon the angle of the sun and whether flying over land or sea. While the fighter pilot cannot control his environment, the environment during vision research is totally controlled.

Vision research and testing is done under controlled circumstances. Tests are conducted on individuals who are usually in a fairly relaxed state both mentally and physically. Conditions are optimized. Although some research has, and is, done to test the results of fatigue, most testing is done on individuals who are well rested. The individual knows where the test is going to take place. That is, he knows that the center of the screen or box or whatever is where he will observe the test stimuli. He is not concerned with having to search for the location of the test stimuli. The spatial orientation of the test is always normal. That is, the test is always conducted where up is up, down is down, right is right and left is left. Other significant aspects in vision testing are mental and physical workloads. Most tests involve the individual sitting in a chair. There is no physical exertion involved. There are no other tasks to demand his attention. He focuses solely on the test at hand with no outside physical or mental requirements. The anxiety level during tests, other than initial screening tests for prospective naval aviators, is usually very low. This same low anxiety level is seen in many trainers and simulators. The individual knows that he is not airborne. He knows that if a mistake is made, it is not life threatening. He knows that it is not the real thing.

While research and vision testing techniques and procedures determine how the eye works and how well it works in relation to some standard, the tests do not closely simulate the actual environment in which the pilot must see.

How does the environment of the fighter pilot differ from the clinical sterility of the researcher?

First, the pilot does not always know where to look. The pilot may not have the benefit of ground controlled radar. Even if he does, with sophisticated deception techniques, this support may be less than optimum. But ground control radar usually only provides approximate range and bearing or azimuth. Altitude information is very seldom provided; therefore, elevation is not known. GCI does not tell the pilot exactly in which piece of the sky the target is located. Onboard radar systems may also be deceived through the use of deception or electronic countermeasures techniques. Additionally, the pilot may not turn on the onboard systems to preclude the target from locating him and possibly using anti radiation measures to attack. However, even if the onboard system is used, it will aid in detecting only one of usually more than one target in the enemy formation. This may not seem like much of a problem, but it is. When on a combat air patrol mission or an escort mission, the pilot must search 360° above and below his aircraft. This requires that he constantly be scanning both azimuth and elevation. There must be some pattern to his scan technique. Otherwise, sections or areas of the sky will not be covered. The scan technique must not be too slow. Aircraft closing at speeds ranging from 1 nm every 6 sec to 1 nm every 3 sec, can move from beyond visual range to within a weapons system firing position in a very short time. An analogy. How many times have you been outside, heard an airplane fly overhead and taken several seconds to find and see it even when it was a large commercial airliner which is many, many times the size of the average fighter aircraft?

One of the tests used by researchers calls for the pilot to determine the orientation of a figure projected onto a screen located directly in front of him. How much more difficult would this test be if the figures were randomly projected onto the ceiling of a domed enclosure? The individual would then be required to first find the figure, then determine the orientation. Sound hard? That is what the fighter pilot does when he searches the sky for other aircraft.

The workload the pilot experiences is heavy. The pilot must fly his aircraft; he must maintain altitude, heading and airspeed. Automatic flight control systems are fine for commercial airliners, but are not of much use for modern aircraft engaged in combat-like maneuvers. The pilot must maintain sight of and communicate with his lead or wingman. He must fly his aircraft as wingman to follow his flight lead or, if he is the flight lead, maneuver the section for optimum utilization. All are cognitive processes. He must process external information sources. Additionally, the pilot must select which onboard systems to utilize and then process the information received.

The physical workload is quite different. The pilot may be required to move around the cockpit in his endeavor to scan the horizon. He must sometimes change the attitude of the aircraft to obtain a clearer view of certain parts of the sky. The largest factor is the addition and relaxation of g forces that he encounters. It is not uncommon to experience two to four positive g's during section maneuvering to either close the target or maintain formation during patrol. And of course after visual sighting, the pilot may experience up to nine positive g's, depending upon the type of aircraft he is flying and the type of maneuvers required.

What other factors distort the clinical observations?

The pilots flight clothing very much alters his ability to see. The flight helmet reduces some amount of his peripheral vision. The oxygen mask also reduces his field of view. This reduction causes the pilot to rely on central spot detection. The visor on the helmet whether clear for low light environments or tinted for bright sunshine or glare from reflected sunlight, interferes with the ability to see the target. The helmet and visor housing and the oxygen mask become significant factors under g loading. If not properly fitted, the helmet can rotate forward, further blocking the pilots field of view. And of course, the helmet and mask both become a weight to be overcome under g loading in order to keep the eye locked onto the target.

Spatial orientation is a large factor in seeing. The mind constantly requires the eye to tell it what the attitude is. Of course, most of this feedback is required after initial target detection. Initial detection of one target does not always result in all targets being destroyed. Therefore, much maneuvering is often required to successfully employ the weapons system. The mind wants to know if the aircraft and it, is ninety degrees nose down, or what the angle of bank is, or the number of degrees to turn to a selected direction. The eye does this by either looking inside the aircraft at the flight instruments or by looking outside at visual cues, usually the horizon. But often times, the horizon is so indistinct because of haze that the pilot must continously look inside the aircraft at his flight instruments to determine his spatial orientation. This time diversion precludes the pilot from looking for and seeing the target.

The cockpit and the canopy are also detractors. The canopy itself, although clear, has a certain amount of translucence to it. The canopy usually has scratches or nicks in it that have accumulated over the years. And, of course, it may be dirty. There are usually structural supports for the canopy around the forward part of the cockpit. While these provide strength and a means to lock the canopy, they present an obstacle to a clear field of view. There may be additional indicators around the front of the canopy. All of these tend to cause the eye to focus in close when looking into an empty space. Most modern aircraft employ a "heads up" display. These systems display information for navigation and weapons system employment. Symbology is normally projected onto the center windshield panel of the canopy. The symbology is focused at infinity. However, the eye can focus on the symbology two feet away and not see approaching targets.

These, then, are some of the differences between tests used to determine the efficiency of the eye in relation to some standard. But technical standards only serve to tell the researcher how eyes perform. Standards do not indicated an individual's ability to perform or to see. Perfect eyes are a requirement for acceptance into the naval aviation program. However, the individual who possesses this perfect vision often is the last person to see the target and once seen often loses sight of it. On the other hand , older pilots with more experience usually get the first "TALLYHO" and almost always never lose sight of the target. Additionally, the naval flight officer, in two seat aircraft, often gains the first TALLYHO. Why? Speculation would submit various reasons. At close ranges, the radar intercept officers task is to look. He already has the radar locked up. He doesn't have to fly the aircraft; all he has to do is look. He can focus all of his energy on this task. He can continuously think about focusing on a distant object and scanning an area. After TALLYHO, he often times maintains sight better. This is because he can twist and turn as necessary to keep his eyes locked onto the target. He is not concerned with flying the aircraft and can spend all of his concentration on maintaining sight.

Earlier, I mentioned that the pilot usually encounters many different visual conditions on each air combat maneuvering flight. There may be haze layers. The sun angle throughout the day causes changing conditions in terms of brightness and glare. Whether the pilot is flying over land or water determines the effects that the sun will have. There may be a high overcast or there may be an undercast. If the fighter pilot has the opportunity, he will position his aircraft so that he can best use the environment to his advantage. Contrast, more than visual acuity, is the primary means that the fighter pilot uses to gain the first TALLYHO. The pilot will position himself, if he has general idea from which direction the target will approach, so as to maximize his ability to discern target contrast in relation to the background. For example, in the afternoon, with a bright glare off the water, the pilot will position his aircraft so that he looks down and onto the glare. Then, any aircraft flying through his field of view will be a dark spot moving across the bright surface. If there is a high overcast, the pilot will position his aircraft so that he is looking up at the light background. Then, any aircraft will appear as a dark speck against the light background. Aircraft engine smoke trails and aircraft contrails are also used to get the first TALLYHO.

The point to remember is that the enemy is probably also optimizing his chances for the first TALLYHO. This means that opposing aircraft because of their similar positions will make an early TALLYHO difficult. Visual acuity comes into play after the TALLYHO. That probably sounds strange, but contrast is the primary initial target detection factor. After the TALLYHO, the identification of the target must be determined. The ability to discern the identification of the target varies mostly as a function of target size and range. In other words, under the same set of visual conditions, the same pilot would be able to identify a large fighter, such as a F-14, before he would be able to identify the difference between small aircraft, such as an A-4 or F-5. As a result, most identifications will take place at or inside minimum weapons firing ranges. This either precludes destroying more than one target, or in the worst case, not destroying any targets. In either case, the pilot will be required to maneuver his aircraft to further employ his weapons system. If the pilot fails to identify the target before it is within this minimum firing range, then dynamic visual acuity becomes important. The aircraft engaged in the dogfight will swirl around one another at speeds ranging from 100 mph to over 600 mph. Distances may range from as close as several hundred feet to three to four nautical miles. The fighter pilot must point his aircraft at the target, in most cases, to successfully employ the weapons system. The g loads encountered during the dogfight cause the performance of the eye to be degraded. Additionally, the pilot must check his airspeed, altitude and other aircraft performance instruments. He must not only look at one target, but often times look at several. He must look for and maintain sight of his wingman or flight lead. He must be aware of the particular weapons system that he has selected. To fire the gun instead of a missile at an aircraft miles away, when the maximum range of the gun is only several hundred feet, will allow the target to escape. The level of apprehension and anxiety are high. The pilot knows that one mistake, one act of losing sight of the target, may well spell defeat. These stresses and cognitive time diversions make his ability to see very different from the relaxed state of the air-conditioned vision testing room.

Experience then becomes a large factor. Experience in looking for the best utilization of the environment. Experience in knowing what to look for when attempting to identify an aircraft. Experience in controlling the level of excitement that flows because of the impending battle. Experience in selecting the correct weapons system and most importantly, experience in knowing where to look. Accommodative flexibility is a must when engaged in the dogfight. The pilot must be able to look inside the aircraft and see the things he wants, then look back outside and see the target. But the target does not stand still while the pilot looks inside his aircraft or looks over at where his wingman should be. The target moves. The wingman moves. Experience allows the pilot to spatially project where the target and his wingman are throughout the dogfight and then see them.

So seeing in the air-to-air combat arena can be improved by experience. Experience should drive the practical application of vision research. Learning about how the eye sees is important but must be translated into useful techniques for the pilot.

NAVAL AIRCREW VISION STANDARDS

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SUMMARY

The United States Navy's aircrew vision standards are as varied as are the skills required in Naval Aviation. Since all preflight training physicals are routinely administered at the Naval Aerospace Medical Institute, the methods of examination as well as the vision standards are discussed. The vision standards discussed in this paper are those pertaining to student and designated Naval Aviators, Naval Flight Officers, and enlisted Naval Aircrew members.

INTRODUCTION

Naval air training is designed to give the college graduate a chance to earn the wings of a Naval Aviator (pilot) or Naval Flight Officer (NFO). There are two basic ways in which one can enter the officer programs in Naval Aviation. One way is through the Aviation Officer Candidate School (AOCS) program where the candidates enter the aviation pipeline as a civilian. These candidates complete a rigorous 13-week course, become Ensigns and then enter aviation preflight training. If they already are commissioned officers when they arrive at Pensacola, they go directly to preflight training.

All officer and aviation officer candidates must receive a physical examination at the Naval Aerospace Medical Institute (NAMI) on arrival at Pensacola. An important part of this examination is the ophthalmology evaluation. Those entering the Student Naval Aviator program receive an evaluation which includes uncorrected distance visual acuity, uncorrected near visual acuity, ocular motility, near point of convergence, stereoscopic depth perception, color vision, and refractive error measurement under cycloplegia. The Student Naval Flight Officer (SNFO) receives an evaluation which includes the same tests as the aviator evaluation except for phoria measurements, near point of convergence, depth perception, and the refractive error measurement under cycloplegia. In addition, the non-aviator evaluation can include distance and near visual acuity measurements with glasses.

METHODS OF EXAMINATION

The visual standards for Student Naval Aviator (SNA) candidates are quite stringent, and accurate measurements are very important. We measure visual acuities in a 20-foot eye lane with specially-made charts consisting of ten rows of 20/20-size letters. Each row consists of two sets of five letters. The chart is constructed in such a manner that the order of the letters can be changed daily or more frequently. We place a photocopy of the chart behind the candidate so that we can observe the candidate during the test procedure. The candidate is not allowed to squint his eyes or take more than 2-3 sec to read each letter. When no letters are missed with either eye, the candidate passes the visual acuity portion of the Student Naval Aviator requirements. If the candidate misses one or more letters with either eye, we repeat the monocular test with the Baylor Visual Acuity Tester (BVAT). If less than five letters are missed with either eye, the candidate returns the following morning for a retest. If five or more letters are missed, the visual acuity is immediately retested with the BVAT using 20/25 letters. When one or more letters are missed on the 20/25 row, we examine the anterior segment of the candidate's eyes with the slit lamp. Next, we measure the intraocular pressures with the non-contact tonometer.

The candidate's near visual acuity, phorias, and depth perception are measured with the Armed Forces Vision Tester (AFVT). When the candidate's near visual acuity is worse than 20/20, we retest near visual acuity at 16 in with a near visual acuity card.

We test the candidate's color vision with the Farnsworth Lantern (FALANT). This test uses three colors (white, red, and green) and consists of nine combinations of two colors. It is conducted at 8 ft under normal room illumination and with random presentations. Next, the near point of convergence (PC) is measured using a near point rule.

After all of the previous tests are passed, the last measurement we make is the candidate's cycloplegic refraction using 1% cyclogyl.

VISION STANDARDS

Naval Aviators are those who are engaged in the actual control of aircraft. Table 1 shows the different groupings of Naval Aviators: SNA candidates, Service Groups I, II, and III. Service Group I aviators are unrestricted in their flight duties while Service Group II aviators are not permitted to make aircraft carrier landings. Service Group III is usually a temporary classification where the aviator must be accompanied by a Service Group I pilot.

TABLE 1

CLASS 1 AVIATORS

	CANDIDATES (SNA)	SG I	SG II	SG III
DISTANT VISION	20/20	20/50	20/100	20/200
		Must be corrected to 20/20 each eye with standard lenses, and that correction shall be worn at all times while flying. Contact lenses are not allowed at any time.		
NEAR VISION	20/20	20/200	20/200	20/200
		Binocular near vision must corr. to 20/20 with corr. available while flying if uncorr. binocular near vision is 20/40 or less.		
REFRACTION	Under cyclo. must read 20/20 with no more than -0.25 to +3.0 sphere or a +0.75 cylinder correction. No squinting.	Not to exceed -1.25 corr. in any meridian. Cyclo. required when vision first falls below 20/20.	NO REFRACTIVE LIMITS.	
OCULAR MOTILITY	Esophoria 10.0 Exophoria 10.0 Hyperphoria 1.5 (Complete Ophth. consult for esophoria/exophoria of 6 or greater, & hyperphoria of 1.0 or greater, to include red lens test.) Point of convergence is required for candidates only. Greater than 100 mm is CD.			(only if indicated) Red Lens Test
DEPTH PERCEPTION	AFVT - no errors in B, C, or D. VERHOEFF - pass 8/8 in 2 of 3 trials. (16/16).			
COLOR VISION	Pass FALANT - Disregard the 1st trial if fails, must average 8/9 on 2nd and 3rd trials. (Must be in lighted room, 8 ft distance and random presentation.)			

The vision requirements for each Service Group are slightly different. While each Service Group has the same requirements for ocular motility, depth perception, and color vision, the visual acuity and refractive error requirements differ. The ocular motility requirements for each group are: lateral phorias (exophoria or esophoria) no greater then 10 prism diopters, vertical phorias no greater then 1.5 prism diopters and a near point of convergence (PC) no greater then 100 mm. If the lateral phorias are greater then 6 prism diopters or the vertical phorias are greater then 1 prism diopters, we require an ophthalmology consultation to determine the cause. This exam includes the red lens test, cover tests, Maddox Rod test and other testing procedures as needed. If the PC is greater then 100 mms, the candidate is retested. If he fails the retest, further evaluation is also required.

Naval Aviators must have no errors in Sets B, C, and D of the AFVT stereopsis test to pass. When there are errors, we retest stereopsis with the Verhoeff Stereopter at 1 m with normal room illumination. There are eight presentations of three bars, one of which is located in a plane either forward or behind the other two bars. This test must be passed with no errors in eight presentations. When this test is failed, we repeat it using sixteen presentations. All sixteen presentations must be called correctly to pass. If this test is failed, we require an ophthalmology workup to find the reason for failing. Naval Aviators must have no mistakes on the FALANT color vision test. If the color vision test is not passed initially, we repeat it twice. The passing score is no more than two errors out of the last eighteen presentations.

Those candidates for the SNA program must have a far and near visual acuity of 20/20 in each eye without squinting. The corrected far visual acuity for Service Group I through III must be 20/20 or better in each eye while the near visual acuity must be 20/20 binocularly. The uncorrected visual acuity for each of these Service Groups differs. The uncorrected visual acuity for Service Group I can be no more than 20/50 in each eye, while Service Groups II and III must be no more than 20/100 and 20/200 in each eye, respectively.

Service Groups II and III have no refractive error limits, but those in Service Group I have a refractive error limit which cannot exceed 1.25 diopters of myopia in any meridian while seeing 20/20. The student's cycloplegic refractions cannot exceed 3 diopters of hyperopia, 0.25 diopters of myopia, or 0.75 diopters of astigmatism while seeing 20/20 each eye. Also, the first time the distance visual acuity of a Service Group I aviator becomes worse than 20/20, he is required to have a cycloplegic refraction.

Table 2 displays the vision requirements for the Student Naval Flight Officer (SNFO) and the designated Naval Flight Officer (NFO). These are the basic vision requirements for aviation officers not engaged in the actual control of aircraft. This classification includes Naval Flight Officers, Naval Flight Surgeons, Naval Aerospace Physiologists, Naval Aerospace Experimental Psychologists, and others ordered to duty involving flying. Measurements of ocular motility and depth perception are not required, but the color vision requirement is the same as that required for aviators. While the SNA and Service Group I refractive error requirements are quite stringent, this group's requirements are quite liberal. The student can have a refractive error not exceeding 5.50 diopters of either myopia or hyperopia in any meridian and no more than 3.0 diopters of astigmatism, enabling him to read 20/20 letters at 20 ft in either eye. Designated Naval Flight Officers have no refractive error limits which enable them to read the 20/20 letters in either eye. Both the student and designated Naval Flight Officers must be able to read 20/20 at near with both eyes together. When the uncorrected distant visual acuity is 20/40 or worse, corrective lenses are required while flying. When the uncorrected distant visual acuity is worse than 20/100, a second pair of corrective lenses must be available while flying.

TABLE 2

NAVAL FLIGHT OFFICERS - CLASS II PERSONNEL

	SNFO	DESIGNATED NFO
DISTANT VISION	Any degree correctable to 20/20 If distant visual acuity is 20/40 or less, corrective lenses must be worn while flying. If vision is 20/100 or less must carry an extra pair while flying.	Any degree correctable to 20/20
NEAR VISION	Binocular near vision correctable to 20/20 and correction available while flying if uncorrected near visual acuity is less than 20/40.	
COLOR VISION	Pass FALANT - Disregard the first trial if fails, must average 8/9 on 2nd and 3rd trials.	
REFRACTION	Not to exceed +5.50 correction in any meridian or exceed $\pm$3.0 cylinder correction. Manifest refraction required when uncorr. DVA is less than 20/40 each eye.	NO REFRACTIVE LIMITS
OCULAR MOTILITY	No obvious heterotropia or symptomatic heterophoria, (NOHOSH).	
DEPTH PERCEPTION	No requirement.	

The Naval Aircrew standards for enlisted aircrew members are displayed in Table 3. Enlisted aircrew members are divided into helicopter and fixed-wing aircrewmen and helo rescue aircrewmen (SAR). The helo and fixed-wing aircrewmen have no requirements for stereopsis, ocular motility, refractive error, or near vision. However, they must have 20/20 distant vision in each eye with or without corrective lenses and pass the FALANT color vision test.

The SAR crewmen, in addition to have a corrected distant visual acuity of 20/20 in each eye and passing the FALANT color vision test, must be able to pass the same stereopsis tests as the Student Naval Aviator, either with or without a lens correction. Also the SAR candidate must have an uncorrected distant and near visual acuity of no worse than 20/50 in each eye while the designated SAR crewman must have an uncorrected distant visual acuity no worse than 20/200 in each eye.

TABLE 3

AIRCREW

	CANDIDATES & DESIGNATED Helo & Fixed Wing Aircrew	HELO RESCUE CREWMAN (SAR) Candidate	Designated
DISTANT VISION	Must be corr. to 20/20. If 20/40 or less, must wear corr. lenses in the performance of flight duties. An extra pair of spectacles shall be available on the person at all times while flying when the uncorrected DVA is 20/100 or less.	20/50 corr. to 20/20.	20/200 corr. to 20/20 & corr. must be available at all times while flying.
NEAR VISION	Not required.	20/50 corr. to 20/20.	20/200 corr. to 20/20.
COLOR VISION	Pass FALANT. Disregard 1st trial if fails, must average 8/9 on 2nd & 3rd trials. (Except CTT, CTR, & CTI).	Pass FALANT. Disregard 1st trial if fails, must average 8/9 on 2nd & 3rd trials.	
DEPTH PERCEPTION	No requirement.	Normal depth perception aided or unaided.	
OCULAR MOTILITY	No obvious heterotropia or symptomatic heterophoria (NOHOSH).		

The Naval Aircrew vision standards are as varied as the skills which make up Naval Aviation. They range from the strict requirements for the Student Naval Aviator to much less strict requirements for the enlisted aircrewman. The Naval Aviator's visually demanding tasks include such tasks as seeing the Fresnel landing light at 1.5 - 2 mi for an aircraft carrier landing, air-to-air refueling, formation flying, and target acquisition, while some aircrewmen may be involved in such tasks as those in airborne intelligence, which is like an office job except that you are flying in an airplane.

Because of the visually demanding tasks of the Naval Aviator, we grant no waivers to those students who fail any part of the vision requirements. Currently, 23 percent of those civilians entering the Aviation Officer Candidate program and 12 percent of those officers entering preflight fail their physicals at the Naval Aerospace Medical Institute. Seventy-five percent of those who fail their physicals, fail because they cannot meet the vision requirements. Most of those who fail have distant visual acuities worse than 20/20 in one or both eyes. The reason that the failure rate is high appears to be due to a laxity in the vision examinations the candidates receive prior to their arrival in Pensacola. We have found that many of those who fail were allowed to squint on previous exams, some have even worn contact lenses. We have discovered that some of the candidates passed either the color vision test or the Verhoeff stereopsis at other clinics because the wrong distance and/or the wrong lighting was used.

In an attempt to reduce the failure rate, we are developing a program to better standardize those facilities that examine aviation candidates prior to the candidate's arrival at NAMI.

PILOT VISION PERFORMANCE NEW REQUIREMENTS

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SUMMARY

Functional visual performance is defined as the ability to gather, analyze, and respond to visual information in an appropriate and efficient manner. The advanced technology of today's aircraft and aircraft systems places a greater demand on a pilot or navigator's visual performance than ever before. Studies conducted at the Air Force Aerospace Medical Research Laboratory (AFAMRL) have shown there exist differences in visual performance in night vision, binocularity, and target detection within a specific classification. There exists a need to develop standardized testing procedures in order to evaluate a pilot's visual skills. With the development of standardized tests of visual skills, the correlation between a pilot's visual skills and his mission performance could be investigated. In addition, research to determine the effectiveness of visual training techniques for improving the various visual skills could be accomplished.

INTRODUCTION

Air Force Regulation 160-43 specifically outlines the various vision tests and the standards for passing the tests for Air Force personnel. These tests include distant visual acuity, near visual acuity, refractive error, contact lens restrictions, field of vision, night vision, and heterophoria or heterotropia. Other tests given which have standards for referral but not rejection are color vision, depth perception, red lens test, and near point of accommodation. In addition, AFR 160-43 also dictates the vision standards for personnel wanting to be either pilots, Flying Class I (FCI) or navigators, Flying Class II (FCII). The purpose of this paper is to explore the area of visual performance as it relates to flying personnel. Vision tests as required by AFR 160-43 will be reviewed and related to various aspects of visual performance. Where appropriate, new tests will be introduced including explanations of their relevance to visual performance. Also, to be discussed will be reports of differences in visual performance within individuals meeting the present requirements of a FCI or FCII physical.

Refraction

Standards for refractive error insure that the pilot/navigator candidate enters the program without any large degree of myopia (plano for pilot, less than -1.50 D for navigator). The standard is not significant in determining visual performance other than uncorrected acuity, which has its own standard.

Distant Vision

FCI standard is 20/20 uncorrected and FCII standard is 20/70 uncorrected, with 20/20 corrected. Visual acuity is an important visual skill that is correlated with target identification. The testing procedure utilized is a static Snellen acuity test. This type of static acuity test conducted in an uncluttered environment, such as an eye examination room, cannot assess the ability of a pilot to identify targets in a dynamic environment such as the cockpit. Studies have been conducted which show the changes in visual acuity due to the haze created by windscreens (1). A dynamic visual acuity test taking into account the visual disturbances caused by the optics in front of the pilot's eyes needs to be developed.

Night Vision

Currently, there does not exist a standardized test designed to test visual acuity at low illumination levels in either the FCI or FCII physical. A pilot's night vision is assessed by case history and/or a dark adaptation test. In a study to determine the light levels necessary for cockpit illumination by pilots in the F-16 and F-15 cockpits, AMRL tested the visual acuity levels of a group of rated personnel using a device called the Night Vision Tester (NVT). The NVT records the light levels necessary for a pilot to correctly identify the orientation of snellen 'E's at various acuity levels. It was found in this study that there exists a significant difference among the pilots in the mean level of illumination necessary to identify a 20/20 target (2). This is important because, during the test section in which the pilots were requested to set the cockpit lights to the level where they were most comfortable, every pilot either matched or exceeded the illumination level necessary for them to see a 20/20 size letter.

In the process of designing a standardized cockpit lighting system, the range of illumination settings may fall outside the limits of a subset of the pilot population. Therefore, it is proposed that a standardized test of low illumination acuity be developed.

Stereopsis and Red Lens Tests

These two tests are being considered together because, in addition to testing depth perception and muscle balance, they also test for suppression. Depth perception tests measure third degree fusion or stereopsis. A lack of stereopsis indicates suppression of the retinal image in one of the eyes. The red lens test measures the mobility of the eyes and the coordination of the extra-ocular muscles while maintaining single binocular vision in the various fields of gaze. The red lens test can also be used to determine suppression and isolate the suppressing eye. Depth perception and single binocular vision are important visual skills used by the pilot to judge distances, as when approaching a runway. With the development of the wide field of view head up display (WFOV-HUD), a pilot is able to view the HUD display and the outside world binocularly. The optics of the HUD were designed with the vergence of the HUD symbology at optical infinity, the same vergence as the world on the other side of the HUD combiner. However, the real world has to pass through the optics of the canopy whose optical power changes the vergence of the real world image, but not of the HUD symbology (3). Therefore, there exists a disparity between the HUD symbology and targets outside the aircraft. This disparity causes either diplopia (of the HUD symbology or a target in the real world) or a misalignment of the sighting reticle with the target. In an effort to determine the disparity limits for single binocular vision, a study was undertaken using a population that had passed a FCII vision test. The range of disparity values determined were 1.2 to 6.2 mrad. An analysis of variance indicated a significant difference among subjects who had passed the vision exam criteria of a FCII physical (4).

Visual skills that can affect a pilot's overall visual performance and that are not currently assessed during flight physicals include eye-hand coordination, facility of accommodation, central-peripheral awareness, and visual reaction time. These skills are required for various tasks that the pilot performs during a mission. Eye-hand coordination is used when flying the aircraft and delivering weapons. It is a skill that can be enhanced by simple training procedures and practice. Accommodation is currently assessed for amplitude; however, the most important aspect of accommodation in pilot performance is accommodative facility. The pilot needs a flexible, accommodative system when changing fixation in and out of the cockpit.

The ability to determine the position of targets in the periphery is important for survival during air-to-air combat. Preliminary tests of baseline visual fields using various target contrast thresholds have found differences in the visual field size (isopter for the target contrasts) among three subjects. An expanded population study should be done to evaluate peripheral sensitivities and to try and correlate them to target detection performance.

Visual reaction time is another visual skill important to the pilot. Today's cockpit is cluttered with instrumentation providing vital information to the pilot; he must have the skill to scan, analyze, and react to the information presented to him. A shorter visual reaction time may, in some circumstances, mean the difference in success of a mission or failure.

The tests currently being used to select and classify pilot and navigator candidates are sufficient to determine baseline vision parameters. Inter-individual differences in visual performance among subjects, within a specific classification, show that the tests currently being used are not appropriate to predict performance for flying visual tasks. The selection and classification process of flying personnel might consider the use of visual skill tests in order to assess the candidate's visual performance abilities. A study to correlate visual skills and actual flying performance might be in order.

Today's visual performance demands on pilots require that we, as a vision research community, continue to advance the knowledge of factors affecting the visual performance of flying personnel. Equally as important is the need to increase research efforts in developing methods, such as vision training techniques, to enhance the visual performance of the pilots and navigators.

REFERENCES

1. Kama, W. N., 1983. The effect of haze on an operator's visual field and his target detection performance. AFAMRL-TR-83-Ø66. Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

2. Perry, M. A., 1984. Instrument luminance requirements under low ambients for fighter aircraft, Pending technical report. Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

3. Genco, L. V. 1982. The measurement of angular deviation and its relation to weapons sighting accuracy in F-16 canopies, AFAMRL-TR-82-6. Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

4. Warren, R., L. V. Genco, and T. C. Connon. 1984. Horizantal diplopia thresholds for head-up displays, AFAMRL-TR-84-Ø18. Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

VISUAL PERFORMANCE AND THE DARK FOCUS OF VISUAL ACCOMMODATION

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SUMMARY

Four widespread visual problems in military aviation are linked to the focusing characteristics and abilities of the observer. These problems involve the necessity of visually detecting and identifying a distant target at the earliest possible moment, viewing difficulties with head-up displays (HUDs), visual complaints and performance decrements that may accompany the extended viewing of visual display terminals (VDTs) and radar scopes, and the myopic progression found in a significant number of cadets and midshipmen during their tenure at the Air Force and Naval Academies. Selection based on the dark focus and the training of personnel in the volitional control of their accommodation using auditory feedback are offered as solutions.

BACKGROUND

The notion that the resting focus of the eyes might not be at optical infinity was advanced explicitly by several investigators in the 1930s. During the 1940s and 50s even more experimenters reported resting or "dark focus" accommodation values at an "intermediate" distance, usually at about arm's length. But it was not until the 1970s with the invention of infrared tracking, laser, and polarized vernier optometers that the dark focus was systematically studied (2,25,28).

During the 1980s, the so-called "intermediate" distance of the dark focus is gradually being recognized as a fact by the scientific community. Its involvements in the "anomalous" empty-field, night, and instrument myopias and in the curious Mandelbaum effect are now anchored to a solid experimental base (2,7,8,12,13,20,27,29). Because all of this basic research was motivated by a need to understand and solve real-world problems, the lag between research and application promises to be unusually short.

DISTANT TARGET ACQUISITION

As either a foveal target or surrounding texture is obscured by reduced illumination, reduced contrast from haze or other atmospheric attenuation, severely reduced field of view, or optical defocusing, stimulus adequacy is degraded and focus lapses toward neutrality. Correspondingly, target detection performance in an empty field is improved when the distance of the target corresponds to the distance of the dark focus (14,21). In the unaided case with a target at optical infinity, a distant dark focus would optimize performance. At any given age, a considerable range of dark foci can be found with those observers who have above average acuity showing the most distant dark foci (15,28). Those observers who possess the accommodative flexibility to focus distant texture should also have superior acquisition performance in textured environments.

VIEWING COLLIMATED DISPLAYS

With the widespread and increasing use of head-up collimated virtual-image displays (HUDs) in aircraft and flight simulators, several problems have surfaced (1,4,9,10,18,32). About 40% of pilots report that using a HUD tends to cause disorientation, especially when flying in and out of clouds. Pilots have also reported a tendency to focus at the near distance of the HUD combining glass instead of on the outside real-world scene. The resulting HUD myopia appears to be a special case of the more general phenomenon known as instrument myopia (7). Whatever the cause, many pilots find it necessary to reaccommodate when shifting attention between HUD symbology and the outside world.

Evidently, collimation releases the eyes to lapse toward the dark focus (8,24), and the bold symbology of typical HUDs does not require sharp focusing for legibility. Thus, collimation does not cause the eyes to focus at optical infinity as the advocates of head-up and helmet-mounted displays assert, and the consequences are the inability of most pilots to attend concurrently to the collimated symbology and distant objects without conscious focus shifting and an associated loss in far acuity and veridical spatial orientation (9).

VDT AND RADAR VIEWING

Surveyed VDT users have reported a large number of visual complaints that include eye strain, visual fatigue, burning and irritated eyes, difficulty in fixating characters, blurring diplopia, headaches, and shooting pains (6,17,30). Many of these complaints are vague and ill-defined. More troublesome, attempts to link these complaints to results of optometric and ophthalmological examinations have failed. Nevertheless, as will be made evident, visual accommodation may be a key component underlying such complaints by VDT users.

Is a VDT display an adequate stimulus to accommodation? Accommodation has been measured for observers viewing hard copy and several types of CRTs and compared to the dark focus (16). All displays, regardless of image quality, caused an accommodative response that was a compromise between the distance of the display and the dark focus. Using a percentage estimate of accommodation accuracy, hard copy corresponded to 82% and CRTs ranged from 52-76% depending on screen size, bandwidth, scan mode, and phosphor. It has been pointed out that current VDTs simply do not provide sufficient contrast for the optimum display of static alphanumeric characters 6).

Accommodative hysteresis or lag has been observed as a result of VDT or radar viewing for air traffic controllers (ATCs) but not for sales clerks and telephone operators (19). For the ACTs, two hours of uninterrupted screen work caused a significant inward shift of the dark focus along with a more "myopic" response to distant stimuli and a more "hyperopic" response to close stimuli. In contrast, the combined responses of the clerks and operators failed to show a significant accommodative effect even though measurements were taken before and after a full working day. Accommodative hysteresis may result from very near accommodation or from the combined effects of moderate accommodation and high levels of stress and concentration found with such tasks as ATC. Chronic stress has been linked to a myopic reaction (28).

While most surveys involving VDTs and vision have sampled civilian office and clerical populations, similar complaints would be expected from a military population. As for accommodation effects, hysteresis could be especially acute under combat conditions in which stress is heightened. Undesirable performance decrements would be expected to accompany both the visual complaints and the hysteresis. Although the contribution of VDT work to the development and progression of myopia has been considered (17), a casual relationship between near work of any kind and myopia has not been established. The dramatic increase in VDT usage at younger ages warrants an answer to this question.

MYOPIA DEVELOPMENT AND FOCUS CONTROL

One of the most prevalent infirmities in modern society is myopia or near sightedness. This ubiquitous disease has been estimated to affect one half to one billion of the world's population (11) and may fairly be characterized as the new wound stripe of urbanized, technical-industrial societies as was once the ulcer. Given the increasing use of the eyes at near distances and the mobility of the visual accommodation neuromuscular system, is this a real disease or simply an adaptive response to an environment that has changed from the broad vistas of the hunting plane to the cramped proximity of man-made symbols? It appears that the new environment is conditioning a response, and the progressive nature of myopia indicates that it does this relentlessly and well (22).

With the new knowledge of the accommodative system being revealed by modern measurement instruments, three major new insights can be identified. The first is the emergence of evidence that the resting position of accommodation is not at optical infinity but is at an intermediate distance. The second is the now amply demonstrated hysteresis in the accommodation response. Revealed previously in static measurement as a "lead" and "lag" of accommodation, it is now clear that, in changing focus, the new state is partly a function of the new dioptric demand and partly a function of the previous dioptric state (3). The third finding is the component of volitional control--unconscious, willed, or trained--in the accommodation response. Training for willed control appears to be easily done, especially with a continuous sampling optometer (23,31). In fact, this motivates a whole new look at incipient, manifest, and progressive myopia as instances of unconscious control.

These new insights suggest that the question is not, "Can we train natural myopes to see better?" but, "Can we retrain behavioral myopes to see better?" And, thus, is it possible to disengage the fragile accommodation response from the strong environmental influences? And, also, is it not reasonable to suppose that emmetropes can be trained for more efficient detection and recognition performance?

APPLICATIONS

There are several indicated applications of all this recently acquired knowledge and an associated need to accelerate our efforts to fill in the holes in our knowledge. Clearly we need to take accommodative abilities, and far as well as near acuity and contrast sensitivity, into account in operator selection and assignment. On the training side, an auditory biofeedback focus-conditioning routine leading to voluntary control has been developed (23). Currently, by teaching young subjects to exercise their acquired voluntary outward focus, Randle has preliminary evidence of both an extension of individual far points and at least partial remissions of behavioral myopia.

As for the selection and assignment applications, it would seem that individuals with distant far points and dark foci should be assigned to jobs in which there is a premium on far acuity, such as sharpshooters and fighter/attack pilots, and that their assignment to close work such as scope viewing should be avoided. Such individuals are too valuable, not only because of their visual prowess but also the outgoing extraversion they tend to exhibit (5). Individuals with dark focus distances within 1 m could be assigned to close tasks with good results, but care should be taken to provide display sizes and viewing distances and perhaps some training that does not result in further myopia.

As for focus training, the possibilities are limitless and in need of immediate exploitation and further study. Without delay, programs should be initiated to train military personnel with good eyes to use them better. Effective techniques for teaching emmetropes to compensate for night and empty field myopia by voluntary focus control have been around for more than 15 years and well publicized (23,26). Training in far-point extension to enhance far acuity and possibly copy better with head-up and helmet-mounted display problems should be investigated in connection with the volitional focus-training. Similarly, training could improve the accuracy of focus to VDTs and radar screens which could alleviate some of the visual complaints and improve performance.

The prevention of myopia in Cadets and Midshipmen should also be given high priority, initially on an experimental basis to discover the least invasive scheduling of focus training in their already crowded days and nights. Another thrust of the experimental program should be toward the remission of already developed myopia in upper classmen and classwomen. Randle's current project under the sponsorship of the National Eye Institute is aimed at improving training procedures for correction of myopia as opposed to the apparently easier task of prevention.

REFERENCES

1. Barnette, J. E. 1976. Role of head-up display in Instrument flight (IFC LR-76-2). Randolph AFB, TX: Aerospace Defense Command, Instrument Flight Center.

2. Benel, R. A. 1979. Visual accommodation, the Mandelbaum effect, and apparent size (Tech. Report BEL-79-1/AFOSR-79-5). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory. (Also in Diss. Abs. Int., 40(10B), 5044; University Microfilms No. 80-09874).

3. Ebenholtz, S. M. 1983. Accommodative hysteresis: A precursor for induced myopia. Ophthal. & Vis. Sci. 24:513-515.

4. Egan, D. and J. Goodson. 1978. Human factors engineering for head-up displays: A review of military specifications and recommendations. Pensacola, FL: Naval Aerospace Medical Research Laboratory.

5. Gawron, V. J. (1983). Ocular accommodation, personality, and autonomic balance. Am. J. Opt. & Physiol. Opt. 60: 630-639.

6. Grandjean, E. and E. Vigliani. (Eds.). 1982. Ergonomic aspects of visual display terminals. London: Taylor & Francis.

7. Hennessy, R. T. 1975. Instrument myopia. J. Opt. Soc. Am. 65:1114-1120.

8. Hull, J. C., R. T. Gill, and S. N. Roscoe. 1982. Locus of the stimulus to visual accommodation: Where in the world, or where in the eye? Human Factors. 24:311-319.

9. Iavecchia, J. H., H. P. Iavecchia, S. N. Roscoe and R. T. Hennesy (In preparation). Perceptual biases with virtual imaging displays. Warminster, PA: Naval Air Development Center, Code 6022.

10. Jarvi, D. 1981. Investigation of spatial disorientation of F-15 Eagle pilots (Technical Report ASD-TR-81-5016). Wright-Patterson AFB OH: USAF Systems Command, Aeronautical Systems Division.

11. Kelley, C. R. 1962. Psychological factors in myopia. J. Am. Opt. Assoc. 833-837.

12. Leibowitz, H. W. and D. A. Owens. 1975. Anomalous myopias and the intermediate dark focus of accommodation. Sci. 189:646-648.

13. Leibowitz, H. W. and D. A. Owens. 1978. New evidence for the intermediate position of relaxed accommodation. Documenta Ophthal. 46:133-147.

14. Luria, S. M. 1980. Target size and correction for empty-field myopia. J. Opt. Soc. Am. 70:1153-1154.

15. Moffitt, K. 1983. Accommodation and the acquisition of distant targets by observers with superior vision. Proc. Human Factors Soc. (pp. 259-263). Santa Monica, CA: Human Factors Society.

16. Murch, G. 1982. How visible is your display? Electro-Optical Sys. Des. 14:43-49.

17. National Research Council 1983. *Video displays, work, and vision*. Washington, DC: National Academy Press.

18. Newman, R. L. 1980. Operational problems associated with head-up displays during instrument flight (AFAMRL-TR-80-116). Wright-Patterson AFB, OH: USAF Aerospace Medical Research Laboratory.

19. Ostberg, C. 1982. Accommodation and visual fatigue is display work. *In*: E. Grandjean and E. Vigliani (Eds.), *Ergonomic aspects of visual display terminals*. London: Taylor & Francis.

20. Owens, D. A. 1979. The Mandelbaum effect: Evidence for an accommodation bias toward intermediate viewing distances.

21. Post, R. B., R. L. Owens, D. A. Owens, and H. W. Leibowitz. 1979. Correction of empty-field myopia on the basis of the dark-focus of accommodation. J. Opt. Soc. Am. 69:89-92.

22. Provines, W. F., W. M. Woessner, A. J. Rahe, and T. J. Tredici. 1983. The incidence of refractive anomalies in the USAF rated population. Aviation, Space, and Environmental Medicine. 54:622-627.

23. Randle, R. J. 1970. Volitional control of visual accommodation. In: Conference Proceedings No. 82 on Adaptation and Acclimatization in Aerospace Medicine (pp. 20.0-20.11). Nuilly-sur-Seine, France: North Atlantic Treaty Organization.

24. Randle, R. J., S. N. Roscoe, and J. Petitt. 1980. Effects of accommodation and magnification on aimpoint estimation in a simulated landing task (Tech. Paper NASA-TP-1635). Washington, DC: National Aeronautics and Space Administration.

25. Roscoe, S. N. 1980. Bigness is in the eye of the beholder. In: Proceedings of the Seventh Symposium on Psychology in the Department of Defense (pp. 39-80). Colorado Springs: USAF Academy.

26. Roscoe, S. N. 1982. Landing airplanes, detecting traffic, and the dark focus. Aviation, Space, and Environ. Med. 53:970-976.

27. Roscoe, S. N. 1984. Judgments of size and distance with imaging displays. Human Factors 26, In press.

28. Simonelli, N. M. 1979. The dark focus of accommodation: Its Existence, its measurement, its effects (Tech. Report BEL-79-3/AFOSR-79-7). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory. (Also in Dissertation Abstracts International, 41(02B), 722; University Microfilms No. 80-17984).

29. Simonelli, N. M., and S. N. Roscoe. 1979. Apparent size and visual accommodation under day and night conditions (Tech. Report Eng Psy-79-3/AFOSR-79-3). Champaign, IL: University of Illinois at Urbana-Champaign, Department of Psychology.

30. Smith, A. B., S. Tanaka, and W. Halperin. 1984. Correlates of ocular and somatic symptoms among video display terminal users. Human Factors. 26:143-156.

31. Trachtman, J. N., V. Giambalvo and J. Feldman. 1981. Biofeedback and Self-Regulation. 6:547-564.

32. Tuomela, C. (Ed.), 1981. Proceedings of the 1981 Test Pilots' Aviation Safety Workshop. New York: Institute of Aeronautics.

PUPIL SIZE AND VISUAL PERFORMANCE

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SUMMARY

This paper discusses pupil size and visual performance from two different clinical aspects. In the first, the pupil is considered as a variable optical aperture. The effect of this aperture on visual performance is summarized in relation to retinal illumination, spherical aberration, and depth of field. These parameters bear a special relation to the conventional clinical practice of prescribing the "maximum plus" finding. When illumination changes the pupil size, visual performance may be significantly affected as well, so these interrelationships are described. The second aspect of the pupil's relationship to visual performance has to do with the pupil considered, not as an optical aperture, but rather as an indicator of iris reflex behavior. A special anomaly of the pupillary light reflex called "alternating contraction anisocoria" is described and related to congenital stereoblindness. The cause of both the abnormal pupil light reflex response and the isolated stereoblindness is suspected to be an anomalous crossing pattern of the retino-cortical fibers at the optic chiasm.

INTRODUCTION

Clinicians consider a patient's pupil in one of two ways. First, it can be treated as a variable optical aperture whose size affects the quality and nature of the retinal image and, thus, visual performance. Second, the pupil can be thought of as just a hole in the iris where it becomes a valuable indicator of the invisible inner neurological status of the patient. This is because of multiple pupil reflex mechanisms by which the iris dilator and constrictor muscles are widely, intimately, and predictably connected to the body's nervous systems. Many special diagnostic pupil reflex tests have been devised to evaluate the status of the nervous systems which are related to iris behavior. This neurological diagnostic aspect of the pupil occupies far more of the vision clinician's time than the optical aspect, presumably because there is very little of routine practical value that can be done to affect visual performance with pupil size therapies. Nevertheless some clinical strategies depend on understanding pupil optics, and we will begin with that discussion.

THE PUPIL AS AN OPTICAL APERTURE

It is tempting and perhaps expected to make some statement about the function or purpose of the pupil's ability to change size. Such proposals seem either to be more statements of consequence than of purpose, or they are awkward to defend. It is more productive, perhaps, to concentrate here on practical optical consequences of optical aperture size change in the human eye.

The most apparent thing about the pupil is the effect light on the eye (thus, on the retina) has on pupil size, and the effect of pupil size on retinal illumination. This is like saying "pupil size affects pupil size" and it surely does. This is dramatically demonstrated by the "pupil cycle time" tests described by Miller (1) where the iris may be made to oscillate under special circumstances where its response creates its own stimulus. Normal pupillary unrest, however, is not caused by retinal illumination changes. The effect of light on pupil size is easily seen; the effect of the change in pupil size on visual performance is not obvious at all. Does the pupil stabilize retinal illumination? In terms of the pupil's ability to compensate for nearly thirteen log units of environmental illumination change, it can not. The most generous estimate of the pupil's ability to affect retinal illumination results in less than two log units of retinal illumination modulation, based on maximum and minimum physiological pupil areas. It is tempting to think it might at least keep foveal illumination constant during eye movements in a visual field full of contrast, but the iris muscles seem much too slow for this, when compared to the speed of saccadic fixational changes. On the positive side, Campbell and Gregory (2) have provided some evidence for Denton's (3) suggestion that for any given level of environmental illumination, and consequent level of retinal light adaptation, resulting pupil size will be that which affords the optimum visual performance. Also, at high levels of illumination, Weale (4) reminds us that pupil constriction might have some protective value against photic damage. Finally, it is possible that brightness discomfort is protective in nature and mediated somehow by pupil light reflex mechanisms. Some of these suggestions might lead to assigning practical value to the pupillary light reflex.

Another consequence of pupil aperture size change has to do with the demonstration that large apertures allow for retinal image light spread due to aberrations, yet apertures too small also result in retinal image light spread due to diffraction at the pupil's edge. An intermediate pupil size seems best, therefore, as discussed by Westheimer (5).

The third consequence is related to the second, because some of the aberrations that result in increased light spread, with large pupils, also have a second effect of altering the eye's power. When illumination falls and the pupil dilates, both chromatic and spherical aberration contribute to an increase in the formerly emmetropic eye's effective power. Chromatic aberration causes blue light to focus in front of the retina, and the Purkinje Shift toward blue sensitivity in reduced illumination causes this myopia for blue to increase in importance. At the same time, most eyes suffer from white light positive spherical aberration, so as the pupil dilates, the eye is myopic for the image formed by the eye's peripheral rays. Flattening of the lens and corneal peripheral curvatures helps reduce the amount of spherical aberration over schematic eye predictions. Hard contact lenses with their spherical anterior surfaces would be expected to make spherical aberration worse. Millodot (6) has shown that to be the case. The rate of acuity loss with increasing pupil diameters was greater with a hard contact lens than without it. Presumably, soft lenses would not show this effect.

The last optical consequence of pupil size changes has to do with the depth of focus of the eye decreasing with larger pupils, and is related to the spherical aberration just described in an interesting way. In providing an ophthalmic correction for ametropia, the convention is to prescribe the "maximum plus" finding, which is the lens with the greatest converging power that allows the patient to see clearly at optical infinity with accommodation relaxed. It is customary to think or say that the patient's eye is then in focus for optical infinity. This is misleading. The conjugate focus of the retina, under maximum plus conditions, can be as close to the patient as one meter or less according to Tucker and Charman (7). Objects at optical infinity appear in focus because they are within the patient's depth of field although at the extreme far limit. Now, consider what happens when this patient leaves the examination environment which is well illuminated and with nice, bright acuity charts. As night approaches, the illumination falls to a point where the pupil becomes larger than when the maximum plus was determined. The depth of field shrinks, and optical infinity is suddenly beyond its farthest limit. The patient is now myopic. Add to this the compounding effects of the myopia of spherical and chromatic aberration, plus possibly a change in posture for the accommodation, and you have a condition of significantly altered perception at distance following pupillary dilation. Even if a target appears that elicits an appropriate and full distance accommodative response, there will still be myopia of purely optical origin as long as the pupil is dilated. Not all people have positive spherical aberration. Having measured the spherical aberration on hundreds of students in the course of a college laboratory exercise, we found the values to be widely variable, including those for some students with negative spherical aberration. A negative value would compensate some for myopia due to depth of field shrinkage, and such a person would be relatively unaffected by the pupil dilation, or perhaps even be a night hyperope instead of a night myope. The only way to know what patients should receive special consideration is to do a vision examination under low levels of illumination. Cycloplegic refractions are a poor alternative to this, and rules of thumb or uncertain prescriptions based on generalized equations can be avoided since the actual personal measurements are simple and superior.

THE PUPIL AS A HOLE IN THE IRIS

Returning now to consider the pupil as a hole in the iris instead of as an optical aperture, we have found a unique and surprising relationship between a special kind of pupil behavior and perception. We first reported this in 1982 (8). We were interested in some new observations by Smith (9) that, contrary to the generally accepted report by Lowenstein and Loewenfeld (10), man's direct and consensual pupil light reflex responses were not always equal, but were different by an average of 6%, the direct response being the greater of the two. Walls (11) had described a similar difference in lower vertebrates, due to the higher percentage of crossed than uncrossed optic nerve fibers at the optic chiasm. The afferent fibers responsible for the pupil reflex branch off from the optic tract right after the chiasm, decussate again, and return most efferents to the pupil in the eye the majority of optic nerve fibers came from originally. Hence, if 75% of the fibers cross at the chiasm and 25% do not, for example, the direct pupil light reflex response should be 50% greater than the consensual response. The difference of 6% in man corresponds to the actual crossing ratio of 53% crossed to 47% uncrossed as reported by Kupfer (12). A report by Creel (13) had already shown that human oculocutaneous albinos were suspected of having anomalous optic chiasm fiber crossing ratios on the basis of asymmetric monocular hemispheric visual evoked responses. A similar chiasmal defect had already been reported in Siamese cats by Hubel and Wiesel (14). The resulting deficit in binocular cortical neurons leads to a loss of stereovision as shown by Crawford (15). Then, in 1975, Guillery (16) proved the existence of this predicted chiasmal anomaly histologically, for one human oculocutaneous albino. Based on our understanding of retinocortical projections in man, such an optic chiasm crossing defect in the human will result in a deficiency of binocularly driven cortical cells, which the visual evoked response study supported. As a consequence of these several different studies, we formed two related hypotheses. First, we hypothesized that human oculocutaneous albinos would show two signs of having an anomalous optic chiasm. One, they would be stereoblind from a lack of binocularly driven cortical cells. Two, they would have unequal direct and consensual pupil responses, called "alternating contraction anisocoria" by Lowenstein (17). Here, the stimulated eye always has more pupil contraction than the other. The second hypothesis was that these rare persons who are isolated stereoblind, that is, stereoblind in the absence of any other related visual sign or symptom, would also have an alternating contraction anisocoria, suggesting the mechanism of isolated stereoblindness to be an optic chiasm crossing defect, as explained before. That possibility seemed promising in the absence of any previously reported satisfactory explanation for congenital isolated stereoblindness. We were able to locate four subjects, two oculocutaneous albino persons and two former students known by us to be isolated stereoblind. The two albino subjects also tested to be stereoblind, as we had hypothesized, using conventional clinical tests plus a more quantitative Howard-Dolman apparatus. Furthermore, using infrared recording pupillometry, all four subjects had the hypothesized alternating contraction anisocoria, equal to or in excess of a 25% difference in the direct and consensual pupil light reflex when either eye was stimulated. Our control group of 10 normals had a average alternating contraction anisocoria of 6%, verifying precisely Smith's results. In addition, our group showed a range of from 1% to 10% difference. the possibility exists that persons with isolated stereoblindness are manifesting by this, some expression of albinism as might be found in ocular albinos. In any case, we believe we have found one verifiable explanation for stereoblindness, which shows a unique relationship between the pupil, or iris behavior, and visual performance in the form of stereopsis.

DISCUSSION

Clinical considerations of the pupil of the human eye involve, first, its function as an optical aperture. It is important to remember that pupil dilation at low levels of illumination can negate the carefully measured maximum plus finding determined in an examination room environment. Reasons for this include pupillary optical considerations of spherical and chromatic aberration effects and depth of field changes, in addition to possible changes in accommodative posture. Second, both stereopsis, and direct and consensual pupil light magnitudes, are related to optic nerve fiber crossing ratios at the optic chiasm of vertebrates. Oculocutaneous albinos were shown to be stereoblind and to have alternating contraction anisocoria. Isolated stereoblind persons with normal cutaneous pigmentation were shown to have alternating contraction anisocoria, an indication that they, too, have a congenital anomalous optic nerve fiber crossing ratio at the optic chiasm.

REFERENCES

1. Miller, M. D. and Thompson, S. H. 1978. Pupil cycle time in optic neuritis. Am. J. Ophthalmol. 85:635-42.

2. Campbell, F. W. and Gregory, A. H. 1960. Effect of size of pupil on visual acuity. Nature 187:1121-3.

3. Denton, E. J. 1956. J. Gen. Physiol. 40:201 (cited in ref. #2)

4. Weale, R. A. 1974. Natural history of optics. In: Davson, H. ed. The eye, Vol. 6, New York: Academic Press, Chap. 1:42-43.

5. Westheimer, G. 1981. Visual Acuity. In: Moses, R. A, ed. Adler's physiology of the eye. 7th ed., St. Louis: The C. V. Mosby Co., Chap. 18:53C-44.

6. Millodot, M. 1978. Effect of the aberrations of the eye on visual perception. In: Armington, J. C, Krauskopf, J., Wooten, B. R, eds. Visual psychophysics and physiology. New York: Academic Press, Chap. 35: 441-452.

7. Tucker, J. and Charman, W. N. 1975. The depth-of-focus for the human eye for Snellen letters. Am. J. Optom. Physiol. Opt. 52:3-21.

8. Chase, W. W., Riggs, J. J., and Ambrose, R. R. 1982. Direct and consensual pupillometry evidence for a crossing defect at the optic chiasm in stereoblind humans. Paper prepared for presentation at the Annual Meeting of the American Academy of Optometry, Philadelphia, December 11, 1982.

9. Smith, S. A., Ellis, C.J.K., and Smith, S. E. 1979. Inequality of the direct and consensual light reflexes in normal subjects. Brit. J. Ophthalmol. 63:523-7.

10. Lowenstein, O. and Loewenfeld, I. E. The pupil. In: Davson H. ed. The eye, Vol. 3, 2nd ed., New York: Academic Press, Chap. 9:255-337.

11. Walls, G. L. 1963. The vertebrate eye and its adaptive radiations. New York: Hafner, 158.

12. Kupfer, C., Chumbley, L., and Downer, J. C. 1967. Quantitative histology of the optic nerve, optic tract and lateral geniculate nucleus of man. J. Anat. 101:393-401.

13. Creel, D., Witkop, C. J., Jr., and King, R. A. 1974. Asymmetric visually evoked potentials in human albinos; evidence for visual system anomalies. Invest. Ophthalmol. 13:430-40.

14. Hubel, D. H. and Wiesel, T. N. 1971. Aberrent visual projections in the Siamese cat. J. Physiol. 218:33-62

15. Crawford, M.L.J, Smith, E. L, Harwerth, R. S., and von Noorden, G. K. 1984. Stereoblind monkeys have few binocular neurons. Invest. Ophthalmol. 27:779-81.

16. Guillery, R. W., Okoro, A. N., and Witkop, C. J., Jr. 1975. Abnormal visual pathways in the brain of a human albino. Brain Res. 96:373-377.

17. Lowenstein, O. 1954. Alternating contraction anisocoria; a pupillary syndrome of the midbrain. AMA Arch. Neurol. Psychol. 72:742-757.

PROBLEMS RELATED TO MEASURING VISUAL PERFORMANCE

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SUMMARY

In quantifying visual performance of a normal population, a number of problems arise which can lead to misleading conclusions about the relationship between different visual functions. Perhaps the most clear-cut examples involve visual acuity, traditionally the most common measures of clinical vision function. Recent interest in the spatial contrast sensitivity function of the eye has highlighted real limitations of classical high contrast Snellen letter acuities "chart acuity" as a description of human vision; however, a number of problems in the method of measurement and specification of Snellen acuity also contribute to apparent limitations in Snellen visual acuity as a performance measure. This paper will highlight some of these problems and implicate them in the reported low correlation between day and night visual acuity, the low correlation to some other measures of vision function, the relatively minor change in visual acuity up to age 55, and the low test-retest correlations sometimes reported for Snellen acuity measures. A case is made for dynamic versions of vision tests in relating to performance in high precision maneuvers and rapidly changing visual environments.

INTRODUCTION

Visual function assessment can be useful in identifying visual abnormalities, diagnosing their basis, and sometimes predicting the subsequent course of a progressive condition. Such measures of vision are applied in the detection, diagnosis and prognosis of disorders of the visual system, and their usefulness need not be dependent on their relationship to a patient's visual performance. On the other hand, tests of vision among the normal population, for example as predictors of daily performance in complex occupational tasks like flying aircraft, need to have a direct relationship to performance in the visual environment. Consequently, visual assessment of medical fitness of the eye and visual pathways may not utilize the same tests as those that are used to predict superior performance in flying an aircraft. Nevertheless, most of the vision tests of visual performance for occupational fitness are descendents of standard vision tests for medical fitness (e.g., high contrast Snellen acuity, visual fields, refractive error, book tests of color vision). For many years, the problems and potential problems of this evolution have been apparent. Some of these problems have been brought to the NRC Vision Committee and have been addressed by working groups. In recent years, there has been a convergence of interest, with legal, clinical and scientific bases, on new tests of vision performance.

With the development of these new tests, there has been a trend to highlight the deficiencies, which are admittedly numerous, of the classical measures of vision. Much of this emphasis is justified. However, I propose that some of the deficiencies lie in the faulty methodological procedures used to make the measurements. In particular, I suggest that (a) the reported low correlations between photopic and mesopic Snellen chart acuities, (b) the low correlation of visual acuity to other measures of sensitivity, (c) the low test-retest correlations reported for Snellen acuity, and (d) the reported minor changes in visual acuity up to age 50, all have measurement diosyncrasies as a significant basis for the conclusion. Of course, strong separate arguments for looking beyond visual acuity for additional tests, useful in predicting performance of normals can also be made; persuasive arguments have already been made for such functions as spatial contrast sensitivity, night myopia (dark focus), motion detection and motion in depth.

After offering data which may account for some of the past conclusions about letter visual acuity, I will then briefly outline a case for more dynamic versions of vision tests.

Correlation Between Day and Night Visual Acuity

Despite much interest in predicting night acuity from day acuity, only a poor correlation has been found (1-5) In general, high contrast letters and single opto-types have been used on subjects with "normal" corrected visual acuities. Correlations between photopic and mesopic letter visual acuity range between 0.22 and 0.37 providing marginal statistical significance and very little practical significance (1,2,5). On the assumption that such poor correlations probably result both from an artificial clustering of photopic acuities and the presence of variable amounts of night myopia, we studied the visual acuity of 40 subjects between 20 and 50 years of age at 2 luminance levels (34 and 0.34 cd/m^2) and with a relatively high contrast target (62%). All subjects had clinical acuities of at least 20/30. Projected white Landolt C's were used in the format described by Flom, et al., whereby a psychophysical method of constant stimuli involving 8 Landolt C's at each letter size was used to generate 50% seeing points from probit analysis. The low light condition was achieved by the addition of a neutral density filter goggle; all subjects were tested for night myopia under this condition and corrected where necessary. Twenty-six required no correction, two -0.25 sphere, nine -0.50 sphere and one -1.00 sphere.

Fig. 1 shows the results of acuity measures made at the two light levels. The Pearson coefficient of correlation was 0.70 ($p<0.001$). The results suggest that a relatively high and significant correlation does exist between photopic and mesopic acuity and that selecting an acuity scale which allows a range of photopic acuity measures, along with correcting night myopia, reveals this.

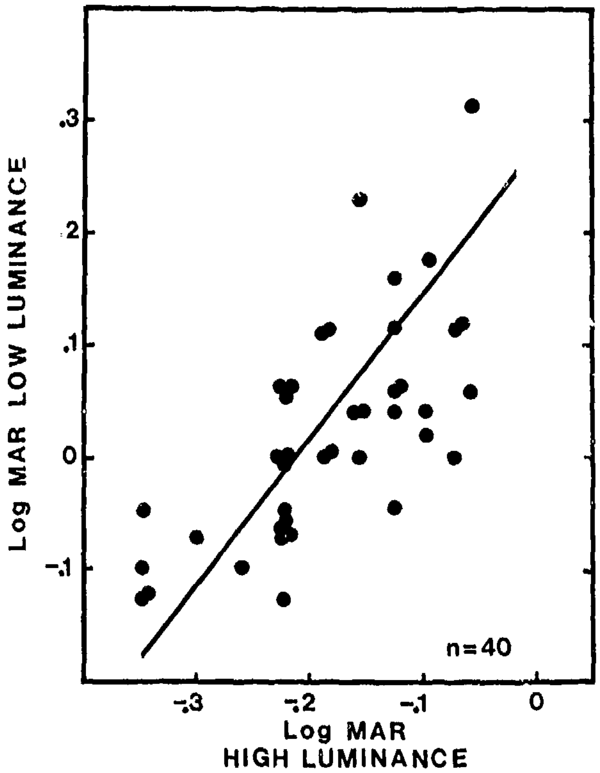

Figure 1. Relationship between high contrast Snellen letter acuity at high and low luminances (34 and 0.34 cd/m2) for 40 subjects between ages 20 and 50.

Fig. 2 and 3 show that both the younger (mean age=24.6) and older (mean age=57) groups have acuities better than 20/20 for the high contrast and high luminance conditions. The older group had a greater reduction in visual acuity for lower contrasts and luminances than the younger group. For example, there was a significant difference (almost 2 Snellen lines) in visual acuity at 54 cd/m^2 with a log contrast of -0.6 (20% using Michelson contrast ratio). Fig. 4 shows that a simple adjustment of contrast within each age group causes the data to fall on the same "template". The adjustment was made based on the contrast sensitivity changes for a 4 min arc spot that occur with changes in the background luminances used in our study (9). Perhaps more interesting is the fact that the same kind of contrast correction between ages, again taken from Blackwell and Blackwell (9), bring all of the data points close to the same template (Fig. 5). In short, visual acuity changes significantly with age, though these changes are not seen with the conventional high contrast letters on a well lit chart. Furthermore, the differences seen with luminance level and age appear to be accounted for by a simple measure of contrast sensitivity to a small (4 min arc) white spot. Low contrast letter acuity has also been shown by us to identify significant differences between diabetics (many without retinopathy) and normals when this difference is not apparent from high contrast letter acuity (10).

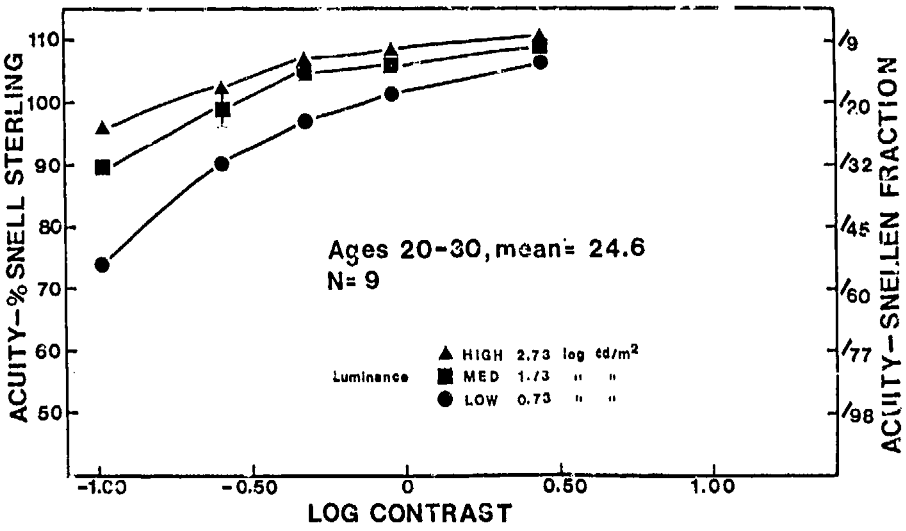

Figure 2. Visual acuity as a function of contrast ($\Delta L/L$) at 3 luminance levels for single Landolt C letters presented in a 4 alternative forced choice (8 letters of each size) format. Fifty percent seeing thresholds derived from probit analysis of frequency of seeing functions. Subjects mean age = 24.6 (2Ø-3Ø years), n-9. Representative $\pm$1 s.d. shown.

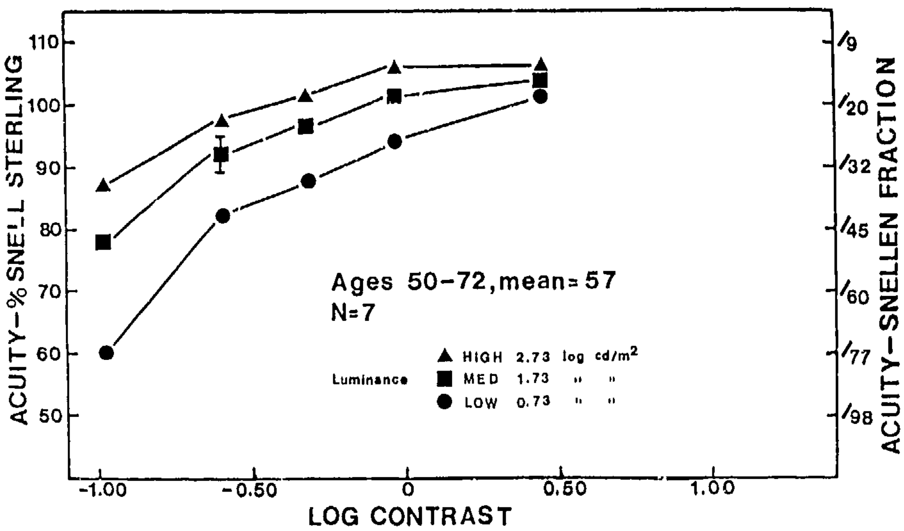

Figure 3. As in Figure 2 except subjects mean age = 57 (5Ø - 72), n=7. Only one subject was over 6Ø year old. Representative $\pm$1 s.d. shown.

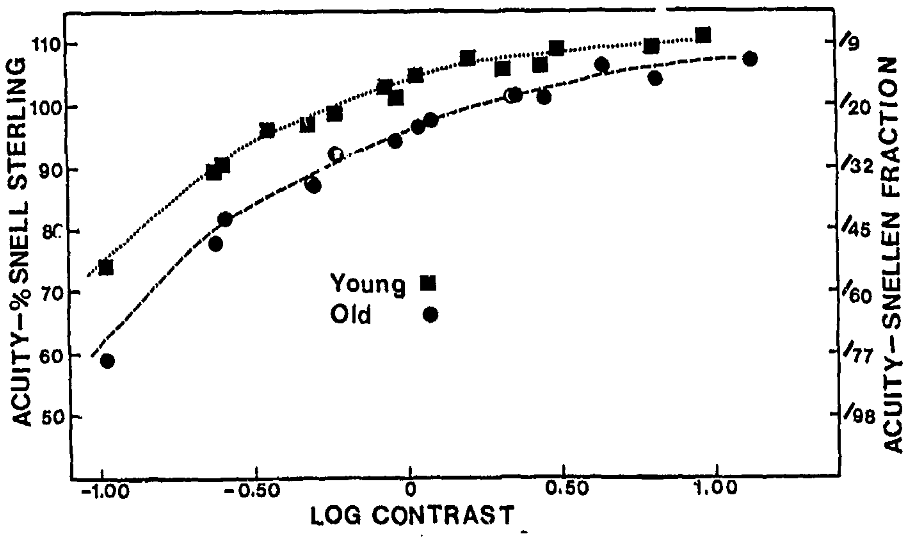

Figure 4. Visual acuity versus contrast for subjects in Figs. 2 and 3. Contrast adjustment, based on contrast sensitivity for 4 min. arc spot (9), has been made within each age group for contrast sensitivity at the 3 light levels (normalized to the low luminance condition.

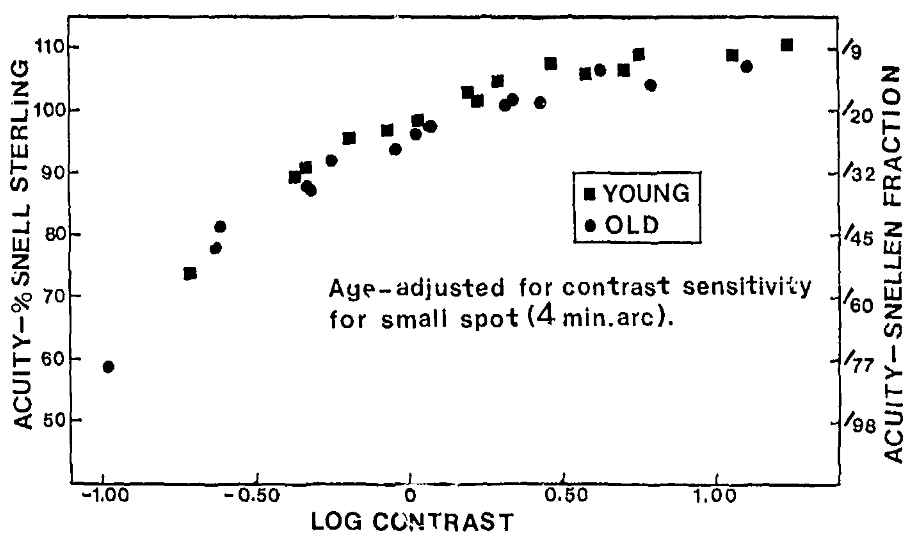

Figure 5. As above except contrast adjustment is based on age differences reported (9). A single 'template' describes all of the acuity versus contrast data at different ages and different luminances.

Visual Acuity Changes With Age

Clinicians report only minor changes in corrected visual acuity with age. Weymouth (7) presented cross-sectional data for 16,675 patients from a single practitioner's office. The data suggest a rather steady and normal acuity up to about age 60, followed by a subsequent decline. In addition, a number of mass screening studies have been performed under a variety of less optimal conditions where pathology and uncorrected refractive errors are included. Even these studies suggest little or no change in visual acuity between ages 20 and 50 (8). A number of factors reduce the effective contrast of the retinal image with age. Together these factors, such as light scatter from the ocular media (cornea, lens, vitreous and retina) and reduced light transmission to the retina (lens and pupil), might be expected to reduce visual acuity. Any changes with age in neural processing in the visual pathways may produce further reductions in effective contrast. However, for photopic light levels letter contrast, above 60-70%, is a relatively impotent variable in determining visual acuity. Consequently, the use of the traditional high contrast (85-95%) Snellen chart is unlikely to lead to measures of visual acuity which are sensitive to contrast reduction, whether they be due to minor reductions in chart contrast (e.g., from soiling) or from reductions in effective retinal image contrast. Therefore, conventional high contrast Snellen testing, which is performed at the usual medium photopic light levels, is likely to suggest that the older eye has no reduction in visual acuity when compared to the younger eye. This conclusion is even more inevitable if it is noted that clinical measures of visual acuity often have an artificial ceiling of 20/20. Clinicians, and others, view 20/20 as normal and often do not attempt to record acuities better than this. (In fact, most individuals have acuities one or two Snellen lines better than this when fully corrected.) With this in mind, we measured the visual acuity of 16 subjects (9 between ages 20 and 30 (mean=24.6) and 7 between ages 50 and 70 (mean=57)) at 3 luminance levels, ranging from low photopic to medium photopic (5.4, 54, 540 cd/m^2), and 5 letter contrasts.

All subjects were referred to the study because they had at least 20/20 corrected acuity, as measured by the referring clinician, and no ocular disease. Acuity measures were made with single white Landolt C's projected onto a white background. Eight Landolt C's were presented at each letter size, and a probit analysis of the four alternative forced choice responses was used to establish 50% correct response levels. Letter contrast was varied with neutral density filters in front of the projector and luminance level adjusted by placing neutral density filters in front of the subjects eye.

Test-Retest of Visual Acuity and Correlation to Other Sensitivity Measures

Although the Snellen visual acuity is the most widely used index of the resolving power of the eye, lack of standardization in format, letter type, and scoring rules often leads to surprisingly low test-retest correlations. Charts with different numbers of letters per line not only make the task different for each acuity level but lead to variable rules for passing performance for each line. Bailey and Lovie (11) reviewed these problems and proposed a new Snellen chart which appears to have addressed most of these problems. Subsequently, scoring procedures were proposed which allowed each letter to contribute to a Snellen acuity score (12). The method is currently used for the National Eye Institute Early Treatment Diabetic Retinopathy Study. The chart has 5 letters on each row, equal logarithmic spacing between letter sizes (0.1 log unit), and maintains the same ratio of letter size to inter-letter and inter-row spacing throughout the chart. Each letter scored contributes 0.02 log units to the log minimum angle of resolution (MAR) visual acuity score. In recent studies, Raasch and Bailey (13) found that 23 normally sighted young adults had a standard deviation of the differences in test and retest of only 2 letters (0.042 log MAR) i.e., 71% were within 2 letters of their first acuity score. Clinicians usually assign Snellen acuity as the line for which the subject sees a given percentage of the letters (e.g., 4 out of 5). Of course, with variable numbers of letters per line and different criterion percentages adopted by different clinicians the reliability will be low. However, even the adoption of a fixed criterion number of letters per line for assigning an acuity on a chart with 5 letters per line leads to surprisingly low reliability. In the same study (13), Raasch and Bailey show that 39% of their subjects would be assigned an acuity _one or two lines_ different on the basis of their repeat test performance. Clearly, scoring strategy has a large effect on the "noisiness" of visual acuity data and surely plays a significant role in test-retest correlations. Obviously, this same induced "noise" in assigning visual acuity scores could exist when visual acuity is correlated to any other measure of visual sensitivity if individual letter scoring of Snellen acuity is not used.

A Case for Dynamic Measures of Visual Function

In spite of the preceding plea for a balanced perspective on the potential usefulness of letter acuity measures, it must be conceded at once that the visual demands in the complex and dynamic environment encountered in flying are a lot greater than can be measured with letter acuity, even in its low contrast (and consequently lower frequency) form. Sensitivity to medium and low spatial frequency (large) objects has already been shown to be highly relevent to target identification and detection (14). Peripheral vision and perception of motion (both lateral and in depth) must also surely play a significant part in overall performance in aviation. In general, dynamic measures of vision and measures of vision under stress (e.g., glare or sudden changes in light level) should also provide strong predictors of performance in these environments. In recent years, we have studied two of these latter functions with an entirely different motivation. In the first, we have measured contrast sensitivity of a small moving spot (5 min arc) and found it to correlate highly with Snellen letter acuity (15). This contrast sensitivity measure of 360 individuals correlated highly with Snellen acuity (r=0.75) and lends itself ideally for rapid, automated and objective endpoint estimates of acuity. It appears to be relatively free of practice effects and is well suited for identifying attempts at malingering or inflated acuity scores. In short, smooth eye movement tracking performance can only occur when the spot is visible; attempts to "fake" these eye movements in the interest of achieving a higher acuity score results, unbeknown to the subject, in jerky saccadic eye movements which are readily detected by the testing instrument or the examiner. In a second task, we have measured glare recovery to the same spot contrast task. Following brief exposure to a large bright field the time course of recovery of contrast sensitivity is tracked over a 30 sec period. This "stress" measure of visual performance is very sensitive to general metabolic disturbance. We (16, 17) and others (18) have shown that relatively low blood alcohol levels can result in significant delays in glare recovery which may be important in driving or flying. We (19) have also shown that the same low doses of alcohol produce significant reduction in dynamic visual acuity (19). In other studies (20), we have also shown that diabetics (including those without retinopathy), hypertensives and women who have been taking oral contraceptives, can have very abnormal glare recovery functions. In all of these studies, the subjects' letter visual acuity was normal. The glare recovery measure appears to be extremely sensitive to a variety of drug toxicities.

In summary there is clearly a need to establish a battery of measures of vision which are most relevant to visual performance in the complex and dynamic environment of flying. Indeed, some functions, including spatial contrast sensitivity, empty field refractive status, and motion detection, already show great promise as relevant emerging measures of visual performance. A review of the idiosyncrasies of letter visual acuity measures suggests that we should be in no great hurry to disbandon it from the test battery in assessing occupational fitness. In fact, careful attention to measurement technique and a consideration of optimal contrast levels for letter acuity tests may revise the current view that (a) day acuity cannot predict night mesopic acuity, (b) acuity does not change significantly between the 3rd and 6th decades, and (c) that test-retest measures and correlations of visual acuity to other sensitivity measures is low. However, our attention should also be directed towards dynamic measures of visual function and measures of visual function under stress. Two examples of such measures, dynamic estimates of visual acuity and contrast sensitivity following glare exposure, are briefly described. The latter test has been shown to be very sensitive to mild drug intoxication (e.g., alcohol, marijuana), vascular disease (diabetes and hypertension) and oral contraceptives.

REFERENCES

1. Kinney, J. A. A. 1963. Clinical measurement of night vision. In: Measurement of Visual Function. Armed Forces-NRC. Committee on Vision, NAS, NRC. Washington, D.C.

2. Ogilvie, J. C., Ryan, J. E. B., Cowan, R. F. and Querengesser, E. I.. 1955. Interrelations and reproducibility of absolute light threshold and scotopic acuity. J. Appl. Physiol. 7:519-522.

3. Pirenne, M. H., Marriott, F. H. C. and O'Doherty, E. R. 1957. Individual Differences in Night-Vision Efficiency. H. M. Stationery Off., London:Med. Res. Counc. Spec. Rep. Ser., No. 294.

4. Schmidt, I. 1961. Are meaningful night vision tests for drivers feasible? Am. J. Optom. 38:295-348.

5. Uhlaner, J. E., Gordon, D. A., Woods, I. A. and Zeidner, I. A. 1953. The relationship between scotopic visual acuity and acuity at photopic and mesopic brightness levels. J. Applied Psychol. 37:223-229.

6. Flom, M. C., Weymouth, F. W. and Kahneman, D. 1963. Visual resolution and contour interaction. J. Opt. Soc. Am. 53(9):1026-1032.

7. Weymouth, F. W. 1960. Effects of age on visual acuity, 37-60 in Vision of the Aging Patient Hirsch, M. J. and Wick, R. E., eds. Chilton Book Co., Philadelphia.

8. Pitts, D. G. 1983. P.144 In: Aging and Human Visual Function Sekuler, R., Kline, D. and Dismukes, K., eds., A. R. Liss Inc., New York.

9. Blackwell, O. R. and Blackwell, H. R. 1971. Visual performance data for 156 normal observers of various ages. J. Illum. Eng. Soc. 1:3-13.

10. Adams, A. J., Zisman, F. Cavender, J. C. 1981. Chromatic, luminosity and contrast sensitivity changes in diabetics. Invest. Ophthalmol. (Supplement) 20(3):92.

11. Bailey, I. L. and Lovie, J. E. 1976. New design principles for visual acuity charts. Am. J. Optom. Physiol. Opt. 53(11):740-745.

12. Ferris, F. L., Kassoff, A., Bresnick, G. H. and Bailey, I. 1982. New visual acuity charts for clinical research. Am. J. Ophthalmol. 94:91-96.

13. Raasch, T. W. and Bailey, I. L. 1984. Choice of optotype and spacing affect visual acuity scores. Invest. Ophthalmol. (Supplement) 25(3):145.

14. Ginsburg, A. P., Evans, D., Sekuler, R. and Harp, S. 1982. Contrast sensitivity predicts pilots' performance in aircraft simulators. Am. J. Optom. Physiol. Opt. 59:105-109.

15. Adams, A. J., Haegerstrom-Portnoy, G., Brown, B. and Jampolsky, A. 1984. Predicting visual resolution from detection thresholds. Am. J. Optom. Physiol. Opt. 61(6):371-376.

16. Adams, A. J. and Brown, B. 1975. Alcohol prolongs time course of glare recovery. Nature 257(5526):481-483.

17. Adams, A. J., Brown, B. and Flom, M. C. 1976. Alcohol-induced changes in contrast sensitivity following high-intensity light exposure. Perc. Psychophysics 19(3):219-225.

18. Sekuler, R. and MacArthur, R. D. 1977. Alcohol retards visual recovery from glare by hampering target acquisition. Nature 270(5636):428-429.

19. Brown, B., Adams, J. J., Haegerstrom-Portnoy, G., Jones, R. T. and Flom, M. C. 1975. Effects of alcohol and marijuana on dynamic visual acuity: 1. Threshold measurements. Perc. Psychophysics 18(6):441-446.

20. Haegerstrom-Portnoy, G., Adams, A. J., Brown, B. and Jampolsky, A. 1983. Dynamics of visual adaptation are altered in vascular disease. <u>2nd Int. Symposium on Visual Optics</u> Springer-Verlag, New York. 225-231.

THE EFFECTS OF A FOVEAL COGNITIVE LOAD MANIPULATION ON THE PERIPHERAL PROCESSING ABILITIES OF NAVAL AVIATORS

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SUMMARY

This paper describes in detail two divided attention experiments carried out on two large samples of naval aviators assigned to the Naval Air Station in Pensacola Florida. In addition, brief mention is made of a third study carried out on a sample of college students. Increasing the foveal load through a memory load manipulation had very little effect on peripheral task accuracy in Experiment I. Experiment II demonstrated that an increase from a 2-set memory load to a 6-set memory load would result in slower reaction times on a number recognition peripheral (secondary) task. Experiment II revealed a "tunnel-vision"-like pattern where an increase in foveal cognitive load had a greater detrimental effect on secondary task performance as the secondary task was presented more eccentrically. It also appeared to be the case that even relatively inexperienced aviators may show better divided attention abilities, i.e., less interference with peripheral task performance than non-aviators. The training and flight experience of these aviators would appear to facilitate dual-task performance.

INTRODUCTION

The functional or useful field of view is an area of the retina within which certain kinds of visual processing tasks can be carried out. The individual's ability to extract peripheral information from a display depends not only on the visual characteristics of displays, but also on the cognitive demands placed upon the individual. Bursill (1), Mackworth (2), Leibowitz and Appelle (3), Ikeda and Takeuchi (4) and several others have discussed the idea of a dynamic functional field of view that depends on the perceptual load of the task.

Williams (5) has argued that the majority of functional field studies have manipulated the visual complexity of the display in some way. Williams (5) found that increasing the foveal (primary) task cognitive load while holding visual complexity nearly constant resulted in a substantial peripheral (secondary) task decrement. Foveal cognitive load was manipulated through the use of the physical and category match levels of a character classification task (6). The present studies represented an attempt at determining whether aviators have the ability to handle a divided attention task without much loss in secondary (peripheral) task performance. Their basic flight activities would appear to provide a great deal of practice in divided attention tasks in general and visual tasks in particular.

EXPERIMENT I

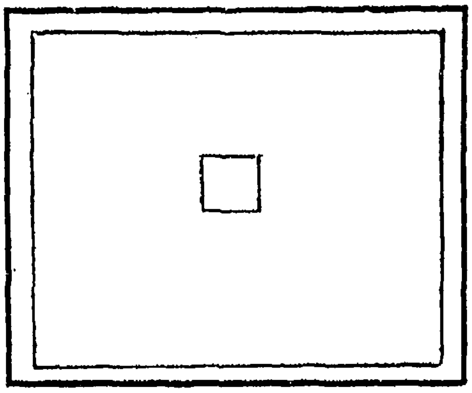
Method

A total of 42 naval aviators were tested in the first experiment. Twenty-one were young officers who were training to become navigational flight officers at the Naval Air Station in Pensacola, FL. They had a mean age of 24.0 years and an average of 72.3 flight hours. The other 21 subjects were instructors from the same squadron, VT-86. These officers had a mean age of 30.6 years and an average of about 1400 flight hours. Eight of these instructors were pilots and 13 were navigational flight officers.

The aviators were tested in the squadron "ready room". The room was well-lighted with overhead fluorescents. Some effort was made to "isolate" the experiment from other activities through the use of temporary partitions, however, there were more potential distractions than in a laboratory setting.

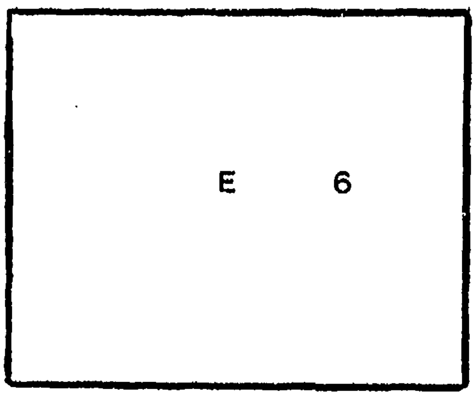
The basic piece of equipment was a 2-channel Lafayette tachistoscope. Stimulus cards were cut from ordinary white posterboard and were 100 mm high and 125 mm wide. There were three sets of stimulus cards corresponding to the three Foveal Cognitive Load conditions. Each deck contained eight practice cards and 48 test cards. Fig. 1 shows examples of several displays.

Subjects looked into the tachistoscope at a white fixation field which contained a small lightly-drawn square in the center. Subjects were instructed to fixate on the square. One second after receiving a verbal "ready" signal from the experimenter, the subject received a 20 millisec presentation of a display (stimulus card). The central letter of the 2-set and 6-set size cards fell at a position corresponding to where the square had been on the fixation card. The peripheral number which could appear at one of 12 equally-likely locations corresponding to retinal eccentricities of 1.5°, 3.0° and 4.5° and the north, east, south and west meridians. The black letters and numbers were from the Chart-Pak series, Helvetica Medium and subtended an average visual angle of 35 ft in height and width.

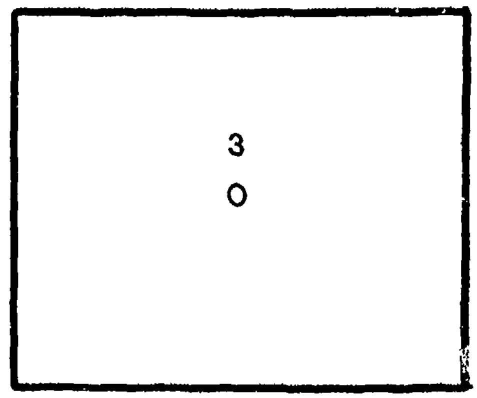


Fixation field

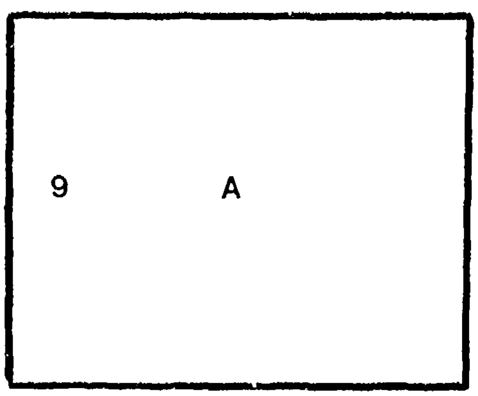
Subjects fixated the central square and had to also be sure they could see the four lines along the border



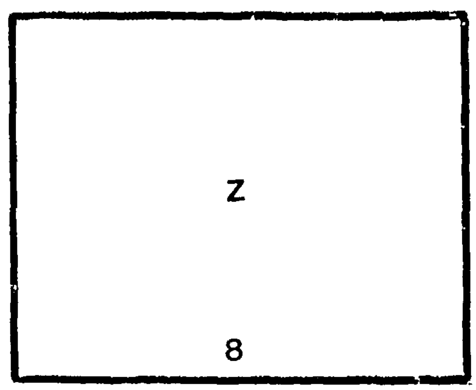
2 set display
correct= positive 6



2 set display
correct = negative 3



6 set display
correct = positive 9



6 set display
correct = negative 8

Figure 1. Examples of several displays

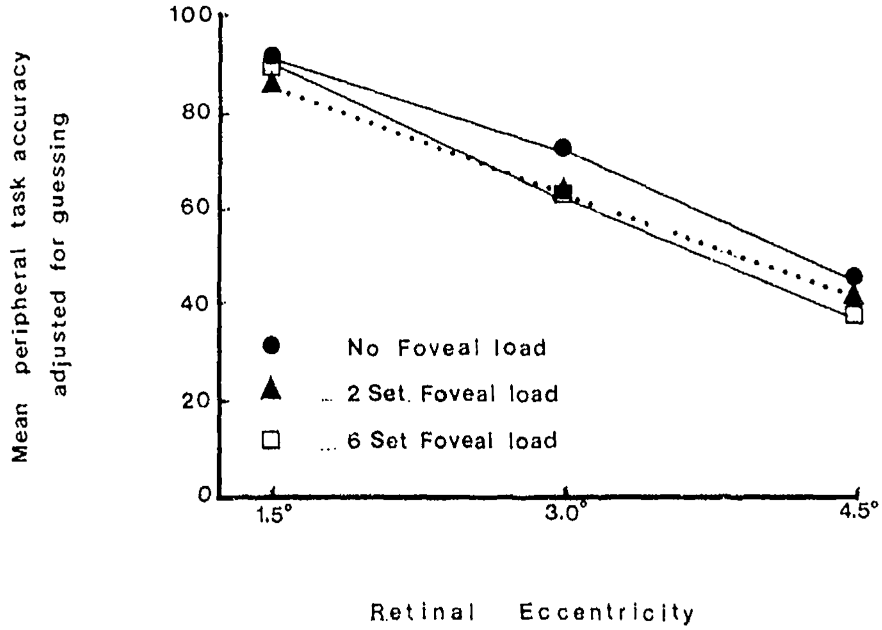
Subjects in the no foveal load condition had to simply state the name of the single digit number that appeared in the periphery The numbers were 3,6,8 and 9 and they each occurred 24 times over the course of the experiment, twice at each of the 12 eccentricity x meridian locations. Subjects in the 2-set size (low load) and 6-set size (high load) conditions had to first state whether the central letter was a member of the positive or negative set of letters and then had to name the peripheral number. In the 2-set size condition, the positive set letters were E and T, and the 6-set size positive letters were A, C, E, P, S and T. The negative set letters were all the other letters which were not used in the positive set.

Each subject received eight replications in random order of the 12 retinal eccentricity by meridian stimulus conditions. The total of eight practice and 96 test trials took approximately 20 min. The experimenter ran through the 48 card deck twice in two different orders for each subject. Subjects received veridical feedback throughout the experiment. Subjects were instructed to respond first to the foveal information and then to the peripheral information.

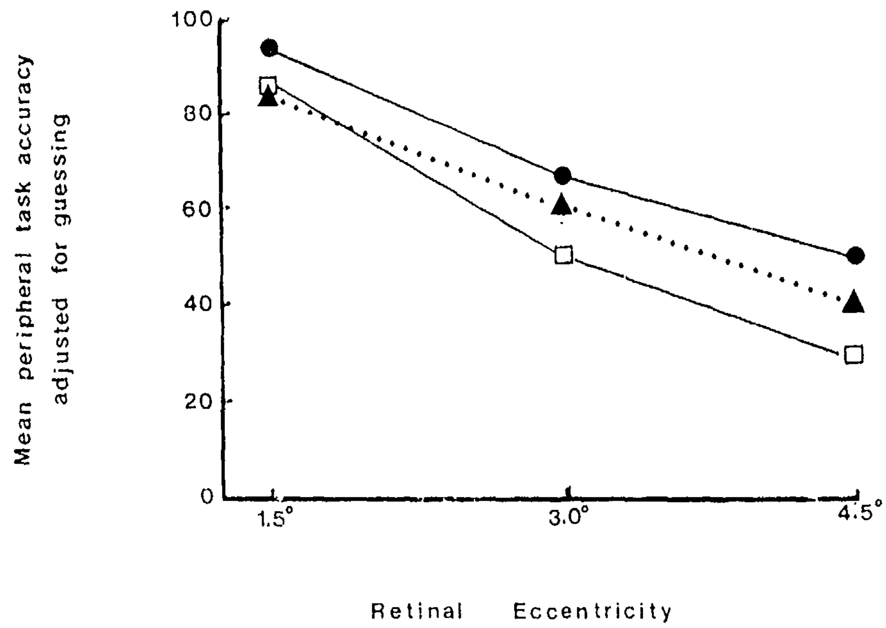
The design, then, had a between-subjects variable of foveal load with three levels. Another between-subjects variable was experience, i.e., student or instructor. Retinal eccentricity and meridian were within-subjects variables.

Results

Subjects made fewer than 2% errors on the foveal task. An overall analysis of variance was performed on the mean percent correct data (adjusted for guessing). There were significant main effects of retinal eccentricity, $F(2, 72)=195.2$, $p<.001$ and meridian, $F(3, 108)=25.8$, $p<.001$. Subjects averaged 89.6%, 66.2% and 41.7% correct (adjusted for guessing) at retinal eccentricities 1.5°, 3.0° and 4.5°, respectively. Subjects performed significantly more accurately on the west and east meridians (74.7%, 73.5%) than on the north and south meridians (57.9%, 57.0%). Neither the experience nor the foveal load variables approached statistical significance. Fig. 2 illustrates peripheral task accuracy as a function of retinal eccentricity with the parameter on the graph being level of foveal load. This figure also illustrates the performance of a college student (non-aviator) group tested on exactly the same task three months later. The very same instructions, materials, equipment, etc. were employed. Because the college students were tested several months later, and in a much quieter environment, we did not combine the aviator and non-aviator data in this paper. There did not appear to be much difference in overall peripheral task performance, however, the college students did have more difficulty on the 6 set-size condition and the college students did show a significant foveal load x retinal eccentricity interaction, indicating a "tunnel-vision"-like effect. Finding no difference between the no foveal load



2a. Aviator accuracy data, Experiment I



2b College student accuracy data

Figure 2. Peripheral task accuracy as a function of foveal load and retinal eccentricity

condition for the aviators and the other two foveal load conditions was a bit surprising. It was felt that Experiment II which employed the more sensitive dependent measure of reaction time and which was designed to be less "data-limited" might tease apart some set size differences in an aviator group.

EXPERIMENT II

Method

The second study was similar in many respects to Experiment I. In this study, 48 naval student aviators were tested in a reaction time experiment. Twenty-four of these were tested with a 2-set size(low) foveal load. The remainder were tested with a 6-set size foveal load. Due to time constraints, it was possible to only collect 48 total test trials per subject, i.e., 4 replications in random order to the 12 retinal eccentricity (1.5°, 3.0° and 4.5°) x meridian (north, east, south and west) combinations. The same stimulus cards and the same tachistoscope were employed.

A right-handed subject sat with the right index finger poised midway between the two buttons. One button was designated "positive" and the other "negative". Subjects pressed a button as soon as they had decided whether the foveal letter had been positive or negative. Subjects rested the four fingers of the left hand over four buttons. Each button corresponded to one of the four single-digit numbers, 3, 6, 8 or 9. The relationship of finger to specific button was counterbalanced. About one sec after the experimenter gave a verbal "ready" signal, the subject saw a display for 180 millisec and which started a millisec clock counting. When the subject pressed the positive or negative button this stopped the clock (clock 1) and started a second clock counting. The second clock was stopped when the subject pressed one of the four buttons corresponding to the peripheral numbers.

An overall analysis of variance performed on foveal reaction times revealed a significant effect of load (set size), $F(1, 46)=6.22$, $p<.05$ with 2-set size subjects averaging 845 millisec on the foveal decision and 6 set-size subjects averaging 970 millisec. There was no significant difference between positive and negative items.

The major analysis was an overall analysis of variance performed on mean peripheral task correct trial reaction times. There were significant main effects of foveal load, $F(1, 46)= 6.70$, $p<.05$; meridian, $F(3, 138) = 3.20$, $p<.05$; and retinal eccentricity, $F(2, 92) = 4.79$, $p<.05$. The 6-set size group averaged 742 millisec on the peripheral task and the 2-set size group averaged 617 millisec. Subjects were significantly faster on the eastern meridian (659 millisec) than on the western meridian (701 millisec). Subjects were significantly slower at the 5.0° retinal eccentricity (711 millisec) than at either the 1.5° (672 millisec) or 3.0° (657 millisec) locations. Note that the foveal load x retinal eccentricity interaction was significant. Experiment II results are portrayed in Table 1 and in Fig. 3. A 6-set size memory load resulted in a substantial peripheral task decrement compared to the 2-set size subjects. The peripheral task performance did not deteriorate for 2-set size subjects in going from the nearest to the farthest location. Six-set size subjects show a reasonably large increase in mean reaction time with increasing retinal eccentricity. This is a "tunnel-vision"-like effect. Some preliminary data recently collected in our lab on college students suggests a steeper slope for 6-set subjects and a moderate slope increase for 2-set size subjects. This, too, looks like the "tunnel vision" pattern. A very small memory load which may not result in a secondary task performance decrement in an aviator population may have a more substantial effect in less skilled individuals. An overall analysis of variance was also run on median peripheral reaction times. The results are quite similar to those already reported.

The overall error rate was rather high, i.e., 21%. The overall analysis of variance was run on only correct trial reaction times. The cell means were computed using a weighted means analysis. An additional analysis of variance was run on the dependent measure of number correct adjusted for guessing. There was a small tendency for more errors to be made at the more eccentric locations. Several additional tests indicated that the homogeneity assumption had not been violated in the reaction time data set.

GENERAL DISCUSSION

Increasing the task demands, e.g., by increasing the foveal cognitive load tends to result in poorer performance on a parafoveal secondary task such as number recognition. The interference with peripheral performance that results from increasing the foveal load appears to be a "tunnel-vision"-like effect. In the second experiment, a high foveal load resulted in a substantial secondary task decrement. A small memory load, however, did not result in a deterioration in secondary task performance as retinal eccentricity was increased. It is easier to demonstrate the effect using a reaction time dependent measure, however, Williams (5,7) has been able to demonstrate the effect with college students using two rather different kinds of foveal load manipulations and using either an accuracy or a reaction time dependent measure.

It appears that aviators may show the same sort of tunnel vision effect as college students, but their daily flying activities may render them less susceptible than individuals less skilled in visual divided attention tasks. It would be interesting to determine which aspects of the aviator's training and flight experience tend to facilitate divided attention performance, particularly those which may result in increasing the size of the functional field. We are currently looking at whether or not college students can demonstrate much improvement in this and related visual divided attention tasks.

Table 1

Mean correct trial reaction times for the peripheral task (Experiment II)

	Low load (2 set)			High load (6 set)			
	Retinal eccentricity			Retinal eccentricity			
	1.5°	3.0°	4.5°	1.5°	3.0°	4.5°	X̄
North	629	545	636	707	712	799	671
East	579	527	644	658	713	833	659
South	668	606	635	709	733	775	687
West	677	637	625	745	779	740	701
X̄	638	578	635	705	734	787	680

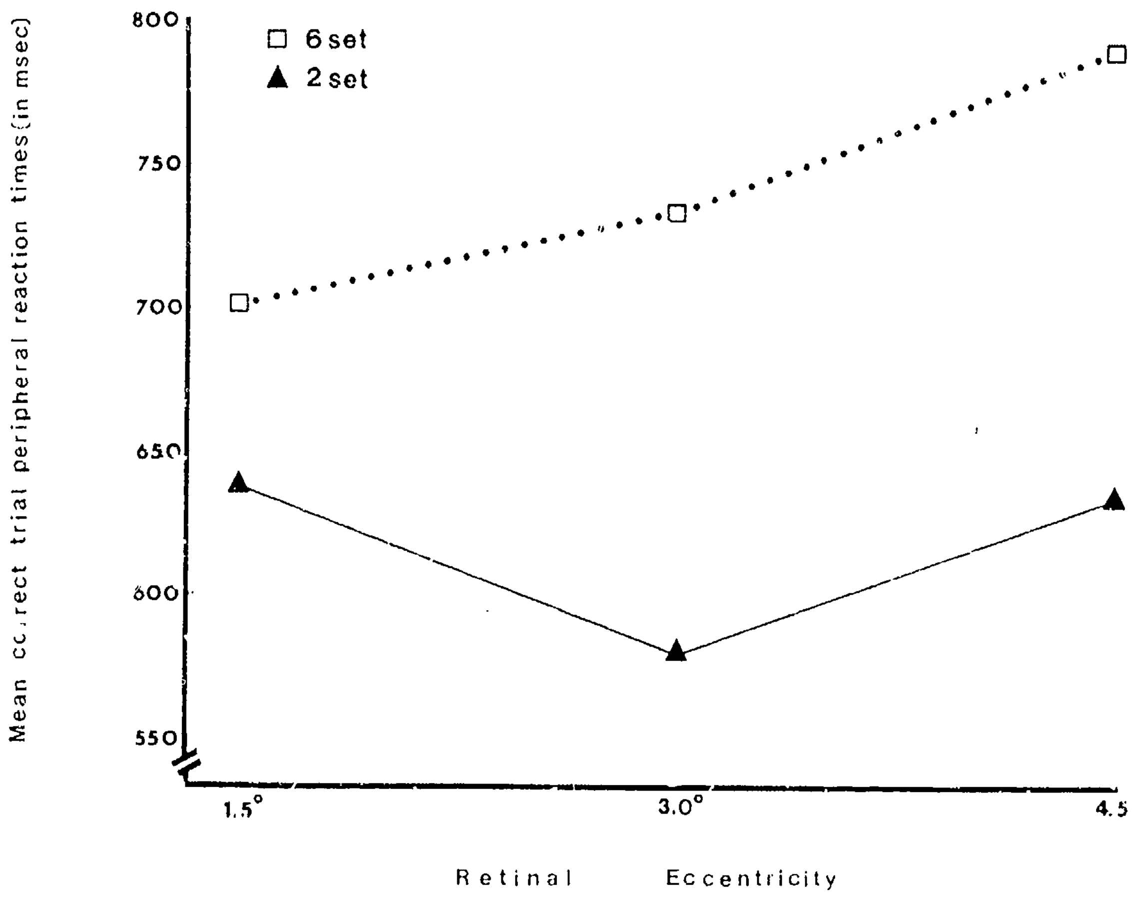


Figure 3. Mean peripheral task reaction times as a function of set size (foveal load) and eccentricity

REFERENCES

1. Bursill, A. E. 1958. The restriction of peripheral vision during exposure to hot and humid conditions. Quart. J. Exp. Psychol. 10: 113-129.

2. Mackworth, N. H. 1965. Visual noise causes tunnel vision. Psychonomic Sci. 3:67-68.

3. Leibowitz, H. W. and Appelle, S. 1969. The effect of a central task on luminance thresholds for peripherally-presented stimuli. Hum. Factors 11:387-392.

4. Ikeda, M. and Takeuchi, T. 1975. Influence of foveal load on the functional visual field. Perc. Psychophysics 18: 255-260.

5. Williams, L. J. 1982. Cognitive load and the functional field of view. Hum. Factors 24:683-692.

6. Posner, M. I. and Mitchell, R. F. 1967. Chronometric analysis of classification. Psychol. Rev. 74:392-409.

7. Williams, L. J. "Tunnel Vision" induced by a foveal load manipulation. (In press).

TECHNIQUES TO ENHANCE AEROSPACE VISUAL PERFORMANCE AND CLASSIFY AIRCREW

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SUMMARY

This paper describes four research efforts that significantly impact aircrew visual performance that are currently under investigation at the Aerospace Vision Laboratory, Ophthalmology Branch, Clinical Sciences Division, USAF School of Aerospace Medicine, Brooks AFB TX. Pertinent information is presented from the Contrast Sensitivity, Night Vision Goggle, Aerospace Soft Contact Lens and Combat Spectacle projects. In addition, several new efforts have been recently initiated that show great promise for classifying certain critical aspects of visual function and may provide the technology to identify aircrew possessing superior performance capabilities. These include the following projects: Low Contrast Snellen Eyecharts, Design For a Comprehensive Night Vision Laboratory, and Mesopic Vision.

INTRODUCTION

The Aerospace Vision Laboratory, Ophthalmology Branch, USAF School of Aerospace Medicine, Brooks AFB, TX is actively investigating many aspects of aircrew visual performance and some new methods for selectively classifying aviators. Several of the most appropriate research projects will be reviewed, including (1) contrast sensitivity, (2) night vision goggles, (3) aerospace contact lenses, (4) aircrew optical equipment, and (5) pertinent new efforts.

CONTRAST SENSITIVITY

The purpose of this study is to develop a broad data base of contrast sensitivity (CS) values accumulated from both an in-house and a contractual project. The in-house project has collected CS data on 120 Air Force aircrew members; the contract project collected CS data on 100 young adults. The objectives were to determine: normal distributions and variability, correlations with standard clinical parameters from a complete ophthalmological examination, and clinical feasibility for widespread USAF use. In addition, CS has been incorporated into the battery of tests in our electrodiagnostic consultation service. Initial cursory analysis of the in-house data (Fig. 1) shows a typical (1) CS curve peaking at 4 cycles/degree. It appears that the variability among individual aircrew members is relatively uniform throughout the range of spatial frequencies tested. Although it is too early to speculate, it is anticipated that complete statistical analysis of the data by age group, aircrew position, i.e., pilots versus navigators, and correlation with ophthalmological parameters will provide some insight into the ability of this technology to classify aviators.

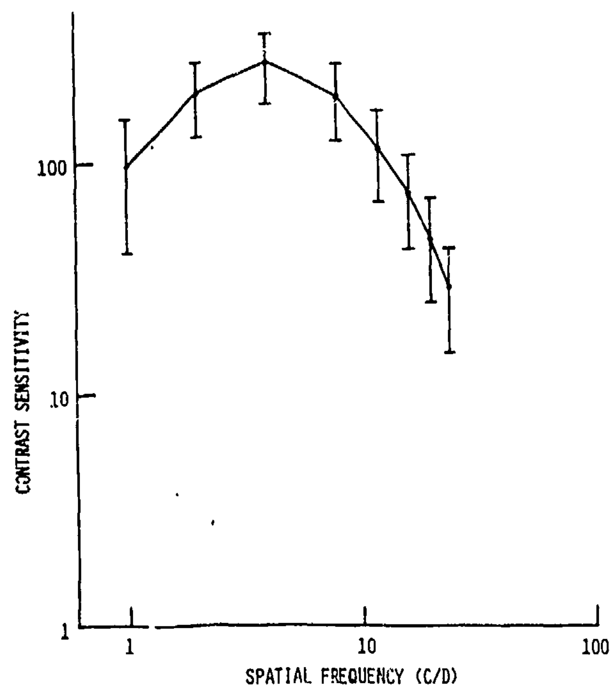

Figure 1. Contrast sensitivity values obtained on 120 aircrew members at USAFSAM. Each point on the curve represents the mean values of the subjects and the bars respresent one standard deviation. Eight spatial frequencies were tested (1, 2, 4, 8, 12, 16, 20, 24) using the method of increasing contrast.

However, it is felt that electronically generated sine wave testing may be impractical for widespread military use because of the significant amount of "down time" experienced with this sophisticated apparatus and the great expense involved. Newer testing modalities, less expensive and simpler in design, show more potential for mass clinical application.

NIGHT VISION GOGGLES

The objectives of the Night Vision Goggle (NVG) project are: to investigate NVG visual performance from the perspective of fixed-wing use; evaluate NVGs under low illumination levels more appropriate to USAF night missions; and support the operational units in the field, i.e., set visual standards and develop screening methods for NVGs.

Accordingly, a field test was conducted under starlight illumination (-10^{-5} mL) comparing GEN II (AN/PVS-5A) and III

(ANVIS) capabilities. Fig. 2 displays visual acuity (VA) data from each of the 10 subjects obtained during that field test. The mean binocular VA value for GEN II was 20/124 and for GEN III was 20/86. This difference was found to be statistically significant at the .01 level (Wilcoxon Test); and, it confirms that the resolution of the ANVIS system remains superior to the AN/PVS-5A even under these low light levels. Figure 2 also reveals that the VA with the NVG under low levels of illumination is significantly less than 20/50, which is commonly referred to as the standard for clinical screening purposes.

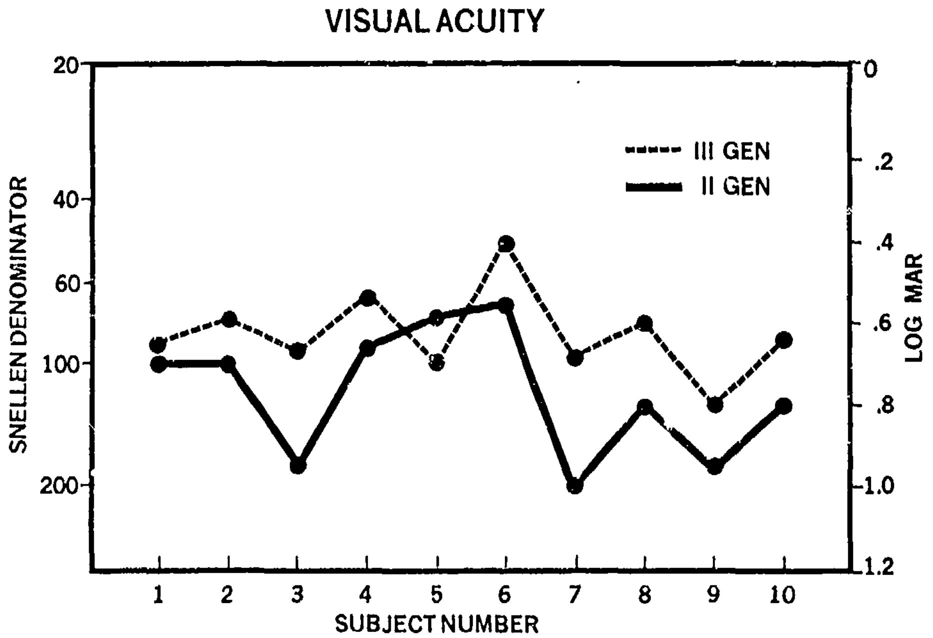

Figure 2. Visual acuity, in terms of minimum angle resolvable (MAR) and/or Snellen denominator, for each of the 10 subjects with both the II GEN (AN/PVS-5A) and III GEN (ANVIS) Night Vision Goggles. The testing was conducted binocularly under ambient conditions of starlight illumination ($\sim 10^{-5}$mL).

One interesting finding of our field testing was the fact that 6 out of 10 subjects subjectively preferred the II GEN NVG even though the VA was significantly better with the III GEN. The reason for this seemingly paradoxical finding was that, under the prevailing ambient conditions, a road meandering through the valley being viewed could not be seen with the III GEN, but it could be seen with the II GEN. This was surmised (2) to be an effect of the differential spectral response of the II and III GEN photocathode tubes and the resultant presence or lack of a contrast gradient with the road and its surrounding vegetation.

In addition to experimental field testing, support to the operational units using NVGs has been continually provided, e.g., a helicopter aircrew member referred to USAFSAM was fit with an extended-wear toric soft contact lens to enable him to continue to fly on NVG missions. He had been grounded because of high monocular astigmatism, which degraded his vision with NVGs, and the fact that spectacles could not be worn because they are incompatible with the face-plate of the AN-PVS-5A. He was returned to full night flying status via waiver for contact lens wear. Also, new methods for setting visual standards and clinically testing visual acuity with NVGs have been designed. One such method involves using modified daylight filters and shows great promise.

AEROSPACE CONTACT LENSES

A recent survey (3) of refractive status in USAF aircrew revealed that 20% of the pilots and 50% of the navigators wore corrective lenses. This trend towards ametropia in pilots is apparently increasing because a subsequent survey revealed that 38% of undergraduate pilot trainees wear corrective lenses. Unfortunately, spectacles are not compatible with much of the equipment that aircrew must use. Several alternatives exist to solve this incompatibility problem: (1) design equipment to be compatible with spectacles, or conversely, design spectacles to be compatible with the equipment, (2) eliminate all ametropes from the flight problem, and (3) utilize contact lenses.

The advent of soft contact lenses with extended wear capabilities now offers many advantages (4) to ametropic aircrew. However, questions arise as to their safety and efficiency in the hostile aerospace environments. This study (5) was designed to be a thorough step-by-step investigation of soft contact lens wear under laboratory and field testing conditions. The parameters to be studied in the laboratory were +Gz forces, rapid decompression, high altitude, altitude and low humidity combined, and chemical warfare agents. The field testing required wear during long term flights. Five subjects were tested wearing three types of soft lenses, i.e., high, medium and low water content lenses. Preliminary results indicate that there are no visual or corneal physiological problems created by these adverse environments. One type of lens, the low water content, did have some peripheral bubble formation with two subjects in the high attitude testing (25,000 ft for 3 hrs). These bubbles did not adversely affect visual acuity and the lens has since been discontinued. The evaluations of altitude and low humidity combined, chemical warfare agents and in-flight field testing have only recently been initiated. Therefore, final judgment as to the feasibility of soft contact lenses must be reserved until all testing is completed.

AIRCREW COMBAT FRAME

An alternative solution to the spectacle incompatibility problem is to develop an aircrew eyeglass frame compatible with all equipment, e.g., gas masks, NVGs, etc. Thus, a contractual project is currently being administered to develop such a frame. Evaluation of this frame prototype (Fig. 3) revealed many improvements over present gas mask inserts such as increased comfort, stability, and field of view. However, many problems

Figure 3. Prototype aircrew combat spectacle pictured with the MCU-2P protective face mask. Notice the flange device used to secure it to the interior of the mask.

NEW RESEARCH EFFORTS

The following are new projects presently being initiated that possess great potential for selection, classification, and identification of aircrew.

Low Contrast Snellen Eyecharts - Can contrast sensitivity technology be easily implemented for widespread USAF use? The highly sophisticated and electronically generated sine wave apparatus has some drawbacks. It is difficult to maintain and calibrate and it is expensive. Patients must receive intensive instructions and technicians have difficulty interpreting data. Several new CS methodologies offer a more pragmatic alternative to apply this technology clinically. Accordingly, a project has been initiated to study the potential of one of these alternatives, low contrast Snellen Eyecharts (6). Testing of normal and abnormal (visual pathway disorders) subjects using this new method and the traditional electronic method will be accomplished and compared. If the correlation is high, the feasibility of incorporating these charts into the present USAF vision screening apparatus (VTA-ND) will be evaluated.

Night Vision Laboratory - Because of increased USAF emphasis on night missions and use of NVGs, a strong night vision research program is needed to support the operational units in the field. Therefore, the development of a high technology night vision laboratory at USAFSAM is proposed. To accomplish this, it is recommended that a working group be created, composed of appropriate national experts, to specifically design this comprehensive laboratory. All aspects of night vision would be addressed and prioritized. Top priority would be directed towards developing a night vision screening system that could be used at the aeromedical clinical level. In this way, standards for night vision could be set and adequately monitored.

Mesopic Vision - Mesopic vision has been somewhat neglected by research investigators, but because it includes ambient illumination levels where some "night vision" occurs, it may be more important than traditional tests of scotopic function, e.g., dark adaptation thresholds. Accordingly, a mesopic vision screening device will be evaluated that has the capability to evaluate resolution, contrast, glare and dark focus. This instrument is a mass screener that is simple to use and could have great applicability to the USAF. This project will test 100 subjects divided into three age groups and compare mesopic visual function with standard scotopic and photopic measurements.

REFERENCES

1. Ginsburg, A. P. 1981. Proposed new vision standards for the 1980's and Beyond: Contrast Sensitivity. AFAMRL-TR80-121. Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, OH 45433.

2. Genco, L. V. 1984. Personal Communication. Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH 45433, Feb. 1984.

3. Provines, W. F., Woessner, W. M., Rahe, A. J. and Tredici, T. J. 1983. The incidence of refractive anomalies in the USAF rated population. Aviat. Space Environ. Med. 54(7):622-627.

4. Miller, R. E. II. 1984. Feasibility of soft contact lenses in simulated flight operation schedules. Med. Svc. Digest. United States Air Force XXXV(1):224-26.

5. Flynn, W. F. 1984. Soft contact lenses in the aerospace environment. Presentation to AMSUS, San Diego, CA, 6 Nov. 1984.

6. Regan, D. and Neina, D. 1983. Low-contrast letter charts as a test of visual function. Ophthalmol. 90(10):1192-1200.

DISCUSSION

DR. BRIGGS: Let me say before I ask you [CDR Hodge], the questions, that it is common not only for pilots, but in a lot of other situations, for people to say that there is something about the job, there is something about that particular task with experience, that makes an older person, even though their vision is apparently not as good, more effective at doing the job. You suggested two explanations for that. One was what I call attention sharing; that is, a younger pilot has to share his attention between flying the airplane and looking for bogies. The other explanation was knowing where to look. Could you give a little insight, particularly for the second explanation about knowing where to look?

CDR HODGE: Let's say that you are practicing basic maneuvers. One airplane is fighting with another airplane and you go by each other and you turn. The first one is trying to get to the other, and you go by and you turn and if I am the old guy I might go up or I might do down or I may just to continue go straight and level. The new guy is probably going to do one thing. He is probably just going to turn, usually level; so he turns level, and in his brain box he says, well, since I am turning level, this guy is going to turn level. But let's say that I go up. He turns, and now he is looking straight ahead when I am up. Let's say you turn and neither one of you sees each other; well, if everybody turns at the same rate, you are going to wind up doing the same size circle and so you wind up pointing at each other after a 360 degree turn. The new guy will turn forever if he loses sight; whereas, the old guy will turn until he knows that he is facing the bogey. I turn and watch the compass until it says that he ought to be out here some place, and then I look outside; but the new guy will just look outside continuously and doesn't have any idea where the guy is and his eyes are wandering around. Even if he went past him, he wouldn't see him because he is moving so fast that his eyes don't have a chance to focus.

So, what I mean by knowing where to look is, in big swirling fight, you know what the other airplane has the capability to do. You know where you are going. If the last time you saw him he was doing something, then you project where he would be across the skies, so that when you look back, he is in a little box and you have a better chance of finding him.

DR. ADAMS: I was interested in the comment that you were within range when you finally made your sightings. Dynamic visual acuity becomes critical. Does anybody sit there in your group and figure what kind of velocities you are talking about in that situation? It would be very interesting to us to know what the reasonable range of velocities would be in that situation.

DR. MONACO: Yes, we have done that. We were initially measuring angular velocities in discrete steps of 20, 50, and 110 degrees per second. Real ACM environs showed us that it didn't seem reasonable for us to consider anything much beyond about 30 degrees per second. So we did some calculations and we found that, there are (when they get in close and tight) angular velocities in excess of 110 degrees per second. They have to be similar to sheer velocities, so it is a realistic problem. It may be, as I mentioned, more for collision avoidance than for defense tactics, but those velocities exist.

DR. ADAMS: Can you just continue on? It sounds like there are two different kinds of task. At the lower velocities you are worrying about sighting and aligning, but at the higher velocities you are just trying to get out of the way.

CDR HODGE: How fast the target tracks across the sky (when you are in close, particularly at the point where the two airplanes pass) is particularly high. When the distances between the airplanes are close (like in a rolling scissors where the airplanes are basically just kind of swirling around the sky in a cylindrical-type evolution) the rate of change of the airplane in position is pretty fast. If the airplane is out there a half a mile away, you are not having to track him very fast; but the closer in he gets (to the pass) and in certain types of maneuvers, the airplane rates are changing fairly fast around one another. It comes into the other question: where do you look when you have positions changing fairly rapidly? You need to look inside every once in awhile to see how much air speed you have, or what the altitude is, or a lot of other things. So, you have got to be able to look inside, find the instruments, and see what they say and then look back outside and see the sky and pick up where you left off.

LCDR HALL: CDR Hodge, could you explain the scanning technique or pattern that works for you, and would you explain what the origin of it was? Were you taught by someone else or did you just discover this on your own?

CDR HODGE: A young guy like LCDR Heatley probably has a scan technique; hopefully you have some idea of where the guy is going to come from, some general area. What I do is pick a distant object like the horizon or a cloud. If you have an island to look at, you look out there and focus on that. Then, look around at a little piece of sky, and if you don't see what you are looking for, look back at your object and focus on that, then pick another little piece of sky to look at. But the point is, with the AIM-7, the AIM-54, and all the weapon systems that we have, and with the superior numbers of airplanes that we are going to be engaging no matter where we go, you have got to be able to shoot the guy before you get together; otherwise, he is going to win just because you are outnumbered. So, it really is important that we come up with some technique to allow us to identify targets (whether good guys or bad guys) far enough away that we will be able to use the technology that we have in the airplanes. If we put all this technology in the airplanes and it boils down to the same things that existed in World War II, where you had to get behind the guy to shoot him with your 45 caliber pistol, then we are wasting a lot of money.

I am sure that somewhere there is a way to take all the things that we have learned about how the eye works and put them into some package which the average Mark-1 model fighter pilot can use to come up with a technique so that he can look out here at two or three or four miles, and so he can, in fact, see what it is that is approaching, and so he can, in fact, tell whether it is a good guy or a bad guy, so we can use the technology.

DR. CHASE: I want to mention something to you and ask you if you can relate to this in any way. Ingeborg Schmidt once made a calculation that if two aircraft are approaching one another at Mach 2, the very instant that you see the other aircraft, in the amount of time it takes for the information to go from your eye to your brain and be processed, that the aircraft is already behind you. Does that effect of high closure rate relate at all to your experience in ACM?

CDR HODGE: We normally run our intercepts with the fighters going Mach .9 plus, and usually the bogeys are Mach .9 plus. So you are pretty close to Mach 2.0 closing velocity. Let's say you see him at 3 or 4 miles. Actually there are 3-4 seconds to look out there, for your eye to see it and go into your brain box and say "that is an F-14," or "it is an F-5 or an F-15" or whatever kind of airplane it is and then do whatever is necessary to use a weapon system. It is not so fast that you can't react to it.

Again, it is an experience kind of thing. With a new guy, it may be that by the time he sees it and gets all excited and decides that it is a bad guy, that the aircraft has passed. After you have been doing it for awhile, you see them at three miles and you are closing at Mach 2; it is not a problem.

DR. MONACO: I have a question for Dr. Chase. That was a really nice discussion of some of the optical considerations that influence or may influence our measurement of dark focus. What about the possibility of these data refuting what Helmholtz said, and what about the possibility of a balance between the sympathetic and parasympathetic systems? It seems that this is a reasonable physiological explanation for some intermediate resting point for accommodation. Can you comment on that?

DR. CHASE: Intermediate resting point for accommodation? Yes, as a matter of fact there are studies also suggesting intermediate resting points for the pupil size, as well as accommodation, as well as vergence. I think the basic message still is this: if you have an intermediate resting point for accommodation and you can measure that, you still cannot ignore the change in depth of field with pupil size changes because that is an independent function. If you start with a small pupil and you measure the far point, you have not measured the conjugate focus of the retina. You are going to have to measure that separately because you can't eliminate the effects of the small pupil. That far point is going to change when the pupil dilates, even if the resting point of accommodation does not change. I think that is really the important thing to remember.

DR. ADAMS: Along the same lines, maybe Dr. Owens or someone could comment, when you make the measurements of dark focus, do you always make the baseline condition from an optometer reading, or do you base it on the person's refractive error (best refraction)?

DR. OWENS: We have done it in both ways. When possible we get best correction at the time of the test; otherwise, we go with the existing correction, provided the subject has acuity of 20/25 or better.

If I could follow up on the last point Dr. Chase made, during your presentation you discussed the fact that increased pupil size increases spherical aberration of the eyes and that ought to induce myopia and may be an important contributor to night myopia. We were familiar with that, and in the beginning we were trying, very hard, to find pupil size effects. Dr. Leibowitz and I did a couple of experiments, and I would be interested in your reaction to them. In one, we measured dark focus through natural pupils, artificial pupils and widely dilated pupils (using Neo-synephrine) and could find no effect of pupil size on our measurement. Secondly, regarding some data I showed yesterday comparing the dark focus with empty field myopia--- of course, our dark measures presumably were taken with dilated pupils. In the empty field, myopia condition was quite bright, so presumably the pupils were not dilated; yet, we found a very tight correlation. I think it was almost .9 between those two measurements.

DR. CHASE: That is really interesting data. I am most familiar with data of the 1950's that shows spherical aberration effects do not increase much beyond pupil diameters of 4 mm. That may very well be why you don't find these changes; but again, the difference between the testing condition in the clinic and the operating condition in the research field may still be within that range. I was very interested in the last speaker, who is again making the suggestion that we have to refine our night vision testing procedures. That should be very helpful.

DR. REGAN: Major Miller raised the question of whether low contrast Snellen charts can be of any practical use, and to what extent they can give the same information as Snellen chart gratings. We have some information on that point. In multiple sclerosis, we have found than an appreciable number of patients have normal acuity and reduced contrast sensitivity at intermediate or low spatial frequencies; and we have recently compared low contrast Snellen charts with gratings in a group of MS patients and find that the low contrast charts can pick out all four categories, two of which are hidden to the high contrast Snellen test, merely by comparing the result of one low contrast chart with the result of the high contrast chart. The tests can also pick up abnormalities in early diabetes.

So, it seems that although it is crude, it is quick, and can pick up gross defects which are hidden hidden to the conventional Snellen test.

DR. PITTS: What percent of contrast is low?

DR. REGAN: We got the thing to work with a high contrast chart of 85% and a low contrast chart of 10%. We get better results if you use an 85% and 5% but some subjects can't see anything on the 5% those two are all you need.

Our experience with 10% contrast Snellen charts for over a period of six years was depicted in my last slide of a cardboard chart (10% contrast) of the Bailey-Lovey design. We found that diabetics too, in the very early stages, are different on that chart than they are on a standard chart. That is, they look normal on a standard chart, but look abnormal on a low contrast chart.

CDR HERRON: Just a quick question for MAJ Miller concerning the rapid decompression in the contact lens study. You went from 8 to 40,000 ft. I might have missed the speed with which the decompression took place and also the time that you remained at altitude.

MAJ MILLER: The 8 to 22,000 was instantaneous and so was the other one with just one subject; a person that worked at the centrifuge tried 8 to 40,000 and it was instantaneous, rapid decompression.

DR. MONACO: This is just a quick question that relates to something Dr. Owens and I talked about a few months ago. One of the factors we are looking at, is trying to tie in a relationship between performance and dark focus characteristics, and we are looking at a range between 0 and -4.0 diopters. One of the things that Dr. Chase mentioned in his presentation was that there is a certain percentage of the population that are hyperopes, or plus value of dark focus measurement. It is interesting, and I am not sure that we have an answer for this, but I would like to pose it to the group. Is there a difference in visual performance between a person that is measured as a hyperope with this machine versus a myopic person? If they have no clues to fixation, then the focus, whether it is in front of the retina or behind the retina, is not going to make any difference in terms of their acuity degradation.

So, what we are saying is that maybe the handicap is there, even in the people that are farsighted.

DR. PITTS: Major Miller, I would like to ask you one question about the difficulties of using astigmatic correction with the soft lenses. Have you looked into the relatively new systems of gas permeable hard lenses.

MAJ MILLER: Yes. The reason we did a soft toric on this person was because we were worried about foreign body problems from the wash, even though he had the full face plate as protection. He could get it when he wasn't wearing the mask, so we went with the soft lenses. Otherwise we would have gone with the gas permeable hard lens.

DR. CHASE: In answer to Dr. Monaco's question, it might seem to some of you that when we are talking about a quarter diopter and a half diopter, that can't be very important; but it can be if your problem is one of threshold. If your task is detection detection at threshold, a little bit of myopia spreads the light out in the retinal image a great deal, and it is going to significantly affect your threshold.

I would hypothesize that the person who is a night hyperope or a night emmetrope is going to perform much better, because he doesn't have this limitation of light spread that you cannot overcome with just your accommodative system.

DR. KINNEY: I have a question for Captain Connon about the light sources in the cockpit, when you were allowing the pilots to adjust for a comfortable level. What were they? Were they bluelights?

CAPT CONNON: They were the backlighted incandescent lighting. White light is more like it.

DR. KINNEY: And the light source for the test?

CAPT CONNON: The light source for the test was an EL panel, which was a blue light, a blue-yellow.

DR. KINNEY: Okay. Well, it may be that part of the discrepancy comes from the spectral energy distributions and the assessment at the mesopic levels of illumination.

CAPT CONNON: That is true. The point of the test wasn't so much to look at the illumination types there were; it is rather that the ghost images created by the cockpit lighting inside the domed canopy of the F-16 were very distracting, and they wanted to get down to levels where those ghost images would be hardly noticeable. The cockpit readings were done with both a black cover over the canopy and under starlight conditions. The pilots maintained dark adapting goggles on when they weren't in the cockpit. There was a change between the starlight con-condition and the cover over the canopy, but it was insignificant in comparison to the change between the night vision tester and the EL panel as opposed to their lighting. We weren't doing a study to compare the spectral sensitivities of the two. Unfortunately, we didn't look at that.

DR. KINNEY: I mean just measurement techniques for the two.

CAPT CONNON: Exactly. That is one of the factors.

GEN RAPMUND: I have several questions for MAJ Miller. I wondered whether you would care to comment on the soft contact lens; the comment you made about CW agent exposure.

MAJ MILLER: Right now, I can't comment on any of our tests because we haven't completed them.

GEN RAPMUND: I am interested in what exactly are you exposing either the lens or people to?

MAJ MILLER: One of our tests is going to be done in the laboratory with the actual agent, and then measuring the concentrations in the lens. I believe that is going to be done at the Army laboratory in Maryland. The other test that we are doing is exposing people to a simulate chemical in droplet form and measuring pupillary changes.

GEN RAPMUND: I am not familiar with the inside of a high performance aircraft and whether there are any propulsion gases, for example, accumulating, but I should imagine that there might be, and that the soft contact lens absorbs them and concentrates them while still in flight.

MAJ MILLER: Yes sir, there have been several studies and some have been contradictory, but there have been several that have shown that it is a source for the nerve agent and so we are very concerned from that viewpoint.

GEN RAPMUND: The next question was going to be whether you have actual field studies, which means pilot or navigator personnel wearing soft contact lenses in simulated missions?

MAJ MILLER: Yes, that is our next phase.

GEN RAPMUND: And when will those start? In the next few months?

MAJ MILLER: Well, hopefully that soon. We are doing it in the C-130's now, so we are having those types of aircrew cargo people wear them and we are monitoring them. But the back seat of attack aircraft is what we are going for next, and that just awaits going through the proper channels, and seeing if they will approve that type testing.

GEN RAPMUND: Then I guess I have a general question or comment, as one who is not in this community at all, but one who is very concerned about the translation of research results into something in the field. When is the last time that there was some modification of vision screening tests based upon the research community activity? And I am not trying to be mean or anything. I am trying to share with you my frustration over seeing the many important things that you address here, and that I have had a privilege of hearing about as I visit your laboratories and yet, finding that the impact on the vision screening community, clinical community, is close to zero. Therefore, that ought to be a useful initiative for the TARP- to bring pressure to bear on the right communities to get some of your methodology on a best guess, not to spend the next ten years figuring out how to do night vision screening better because -- the same principle applies in many other parts of the R&D program. But I would certainly bring my command support across the services to the introduction of any new screening procedures, realizing how terribly difficult it is when you start dealing with AFI stations. It is not the same as dealing just with an aviation community or some other special community. It is at the AFI station where we really need to implement some of these procedures so that you identify the trainables and the special qualified personnel.

NOTE: General Rapmund's question is answered in LT COL Genco's presentation. The Presentation describes automated vision testing devices being constructed to address the General's specific question. This device will be delivered to NAMRL/NAMI for testing in December 1984.

IV. AUTOMATED VISION TESTING

VISUAL SKILLS JOB ANALYSIS AND AUTOMATED VISION TESTING

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SUMMARY

A visual skills job analysis was carried out in which job depictions were used to elicit importance rankings and critical incidents from 155 incumbent officers. In parallel with this effort, a computerized automated test package was created which would represent a broad range of visual skills. Fifty-two naval navigator students and pilots were screened on this package. Results of the job analysis and the test package suggested that a test package which emphasizes dynamic, time contingent, and illumination related skills would be most likely to effectively screen those involved in visually demanding tasks.

INTRODUCTION

Peace officers are typically selected on their presumed ability to work patrol. This "patrol officer" job has recently been studied extensively at the California Commission on Peace Officer Standards and Training (1). An outgrowth of this work has been a major empirical study to examine the feasibility of new selection standards for peace officers based on job performance--job related standards. Among the selection standards evaluated in this way were vision standards.

Traditionally, visual standards have been rational standards based primarily upon presumed medical conditions: one looks for ocular defects; in their absence, one presumes that visual functions and visual performance are normal--adequate to do the job. The most commonly used screening tests involve static far acuity, sometimes supplemented with a test of color vision (2). These tests have unquestioned value to optometrists and ophthalmologists in prescribing optical aids and evaluating visual anomalies.

Unfortunately, efforts to extend the clinical benefits of static far acuity testing to selection procedures and standards have been less than successful. The fundamental problem seems to be that clinical definitions of optical imperfection fail to correspond with behavioral measures of visual performance. Related concerns involve differing ways of measuring acuity and the difficulty of establishing reliable and valid measures of performance. Still another dilemma involves differing techniques for achieving "correction," ranging from surgery to spectacles.

On July 7th and 8th, 1983, a workshop was held at UC Berkeley to consider these problems (3). Participants consisted of visual scientists and other researchers representing the military, veterans, police and the National Academy of Sciences. The central concern was developing a validation strategy leading to work-related visual standards. These were areas of consensus:

1. Standard Snellen acuity is an outdated, misleading, and extremely limited basis for standards which must be indicative of performance.

2. One should proceed logically from job analysis to test development.

3. An appropriated standard should consist of a relatively small number of reasonably simple, well established performance tests.

4. Automated testing would be the most practical and reliable way of implementing a large scale screening standard.

5. Any definitive vision standards project would require extensive criterion and test development.

The magnitude of the problem and the limits of our resources (both in time and funding) led us to focus our resources on two tasks: a truly visual job analysis, and the development or a new, inexpensive, portable automated visual test package. It was hoped that these two efforts would converge on a recommended job-related visual standard for peace officers with implications for other visually demanding occupations--such as military pilots.

METHOD

Visual Skills Analysis. Since the activities of patrol officers had been extensively studied, a reanalysis of the Kohls, et al. (1) data was initially carried out. In this data, patrol officers were shown to use visual skills extensively on the job--both in typical and critical incidents. However, specific details of how vision was used were not available. Since amount of lighting, source of lighting, time contingencies, and visually critical aspects of the task were necessary to evaluate the visual demands on the patrol officer, a further visual skills analysis job was considered crucial. The major obstacle to further visual analysis of the job was the difficulty faced by the officer in evaluating relevant but highly technical aspects of vision in the context of typical and critical incidents on patrol. After numerous ride-alongs with individual officers, elaborate interviews with incumbents (alone and in groups), and consultation with other researchers who faced similar difficulties (4) the following approach evolved. Visual performance was broken down into six activities which, in turn, consisted of individual visual skills--seventeen in all. Each of these activities and skills were depicted photograpnically--based on real incidents and using law enforcement personnel and vehicles as much as possible. Incumbent officers rated and ranked these depicted activities in terms of importance to the job.

Following each of the six activities, officers were given opportunities to provide critical incidents in which vision played a crucial role. Technical details of specific visual relevance were gathered on a critical incident form (lighting, terrain, distance, surroundings, etc.). Each officer spent approximately three hours viewing the depictions and providing information. A total of 1251 critical incidents were gathered and evaluated in terms of visual skills.

Automated Visual Test Development. A list of possible visual tests were collected. They included tests currently administered for standards, newly emerging tests, and tests which have been part of other research programs. These tests were evaluated both in terms of their own merit and their usefulness as components in an automated visual test package. Tests that were considered included: near acuity, far acuity, dynamic visual acuity, acuity with glare, contrast sensitivity, color vision, visual choice reaction time, visual simple reaction time, automated perimetry, phorias, stereopsis, and dark focus. Excluded from serious consideration were direct testing of the oculomotor system (saccadic or other eye movement, pursuit rotor, accommodation time), cognitive/perceptual tests (imbedded figures, rod and frame, binocular rivalry), and physiological measures (visual evoked potential, GSR, electro-oculograms, etc.). Although other test packages were carefully reviewed (5,6,7) many visual scientists were interviewed, and consultants made formal recommendations, it was extremely difficult to agree on even a possible test battery. Our decisions were ultimately based on two pragmatic considerations. First, we chose tests which could be implemented together in an automated form and required limited instrumentation. Second, we chose tests which were reasonable brief and easy to administer. One consequence of this approach was to defer the development of tests with dynamic targets, but not time contingent responses.

After considerable discussion, the following tests were assembled into an automated video display test package: three types of acuity (high, low, reversed contrast), visual choice reaction time, visual search, and contrast sensitivity (with method of adjustment and two item forced choice). Various versions of this package were also to be paired with a glare source, creating a glare tolerance test.

Tests not amenable to VDT displays (automated perimetry, near acuity, stereopsis, and color vision) were to be integrated into the automated test package at a later point--if appropriate. Fig. 1 shows a prototype version of an automated testing device which could include all the tests described above. At this point in research and development, these components remain to be integrated.

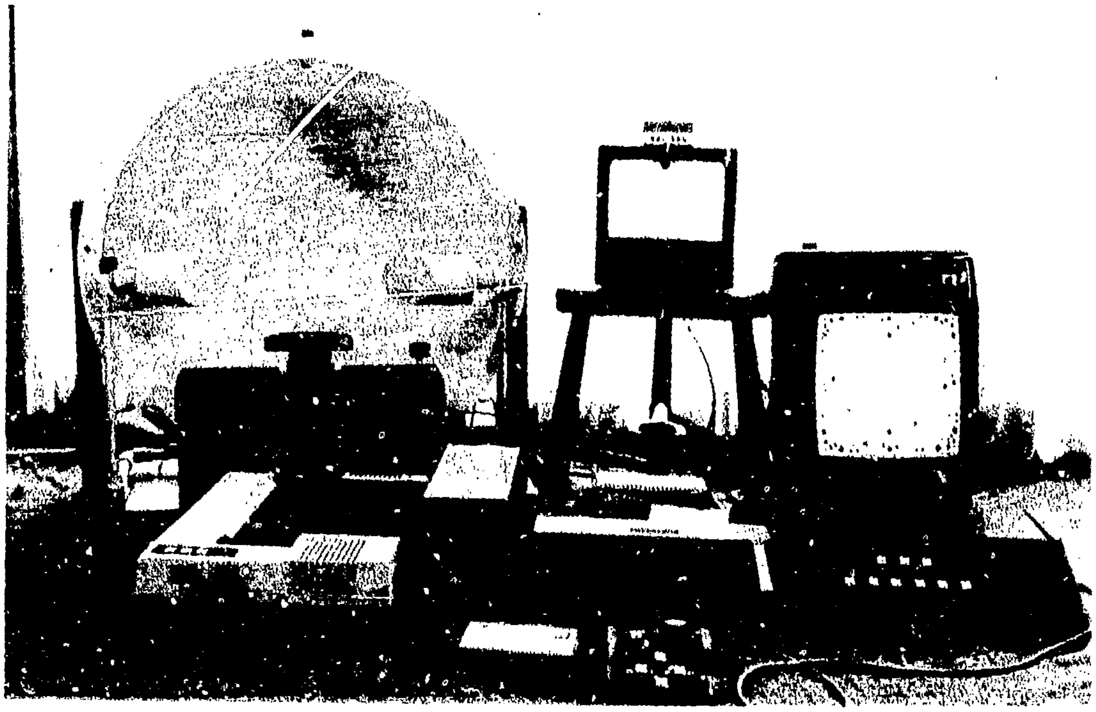

Figure 1. Prototype version of an automated testing device.

The research and development process has so far consisted of four major phases:

1. test development
2. test modification
3. field testing
4. test reorganization/field validation

Since field validation data is still being collected, this aspect of the project will not be discussed here.

The first data was collected on 44 college students at UC-Davis. Students were tested on those tests which were best established at the time (acuity and contrast sensitivity) for the reliability of the tests. Since subjects "bottomed out" on acuity tests, did not have noticeably different scores on the tests with glare or low contrast, and since the contrast sensitivity tests were far too time consuming to be usable, the specific results will not be reported here. However, these results have guided subsequent modifications of the test package.

Following some modifications of the test package, a second set of data was collected in the ready rooms on navigators and pilots under adverse circumstances (lighting, distractions, etc.). A more complicated package of tests was used than at UC-Davis (high and low contrast acuity, choice reaction time, visual search). Rather than establishing test-retest reliability, emphasis was placed on the intercorrelations between the tests and more established acuity measures (high contrast far acuity) as well as the feasibility of a portable testing device in terms of testing time, difficulty of administration, interest of the pilots and navigators, and the reliability of the device. The testing distance for acuity was increased to 10 ft.

RESULTS

See Tables 1 - 3

Table 1 presents the perceived importance of the 17 visual skills for the job (importance rank) and the actual frequency of each skill being used in the critical incidents (critical frequency). A total of 155 incumbent officers from throughout California participated. Table 2 presents the mean scores of Navy pilots and navigators. Table 3 presents the intercorrelation between the tests administered to Navy pilots and navigators. Data reported in Tables 2 & 3 involves best corrected vision with both eyes, N=52, mean age = 26.5.

DISCUSSION

Importance rankings and critical incident frequency data have several interesting features in common. Static far acuity and color discrimination, the two skills most commonly tested using rational standards are ranked low in importance (14, 17) and are seldom skills involved in critical incidents (49 and 16 out of 2003). Frequent acuity related skills seem to be illumination dependent and/or dynamic in nature. Adjustments to light and dynamic skills were related as very important. Tables 2 and 3 tend to show that even in an early form and when testing was carried out under adverse conditions, automated testing correlates quite well with traditional acuity testing. Only visual search (perhaps the least reliable test) failed to intercorrelate substantially. Although intercorrelations between acuity and reaction time might suggest common skills, an alternative explanation would be that forming an optical image is a necessary but not sufficient basis to explain dynamic aspects of visual behavior.

Based on this data and other information, the automated test package was modified. Testing distance was increased to 4 m and the target was optically made smaller, the contrast level of low contrast acuity was reduced, a new glare source was developed and paired with contrast sensitivity, contrast sensitivity was simplified and the forced choice method employed. This modified package is currently being evaluated along with many other tests for test-retest reliability, comparability, and possible relationships with self report criterion. New dynamic tests are being considered to supplement the package.

TABLE 1. Visual Skills Analysis

Visual Skill	Critical Frequency	Importance Rank
Identify objects	322	7
Pursuit	273	13
Motion detection	231	3
Dynamic far acuity	201	11
Dark adaptation	200	1
Peripheral vision	145	2
Glare tolerance	127	5
Fine details/various light levels	117	9
Depth perception	88	8
Color identification	75	15
Accommodation	56	12
Static far acuity	49	14
Light adaptation	42	4
Dynamic near acuity	32	10
Color discrimination	16	17
Identify large forms	15	16
Glare recovery	14	6

TABLE 2. Pensacola Navy Automated Test Scores

Test	Mean Value
Armed Forces acuity	20/19
Automated acuity*	20/16
Low contrast acuity**	20/18
Automated choice reaction time	.849 S.D. .108
Automated visual search	2.866 S.D. .779

*40 scored lowest possible score
**20 scored lowest possible score

TABLE 3. Intercorrelations Between Tests

Test	AF	Auto Acuity	LC	CRT	VS
Armed Forces acuity	X	.5372	.6399	.3674	.1601
Automated acuity	.5372	X	.6203	.3293	.0138
Automated low contrast	.6399	.6203	X	.2369	-.0604
Automated choice reaction time	.3674	.3293	.2369	X	.2908
Automated visual search	.1601	.0138	-.0604	.2908	X

REFERENCES

1. Kohls, J., J. Berner, and L. Luke. 1979. California entry-level law enforcement officer job analysis. Sacramento, CA, the California Commission on Peace Officer Standards and Training, 1979.

2. American Optometric Association, Vision Standards Bibliography. St. Louis, MO, Am. Opt. Assoc. 1981.

3. Briggs, R. R. 1983. New vision validation strategies - some reactions to the UC, Berkeley Workshop, the Commission on Peace Officer Standards and Training, Sacramento, CA, August 1983.

4. Nylander, S. W. 1983. Visual task analysis manual, San Bernardino, CA, Advanced Personnel Management Systems.

5. Henderson, R. L., and A. Burg. 1974. Vision and audition in driving. Dept. of Tran. Nat. Highway Traffic Safety Admin., Washington, DC.

6. Shinar, D. 1977. Driver visual limitation, diagnosis and treatment, Nat. Highway Traffic Safety Admin., Washington, DC, May 1977.

7. Morris, A. and J. E. Goodson. 1983. A description of the Naval Aerospace Medical Research Laboratory vision test battery, Pensacola, FL.

AUTOMATED VISUAL FUNCTION TESTING

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SUMMARY

This paper describes three of a series of Visual Function Test (VFT) instruments being constructed and tested in-house at the Air Force Aerospace Medical Research Laboratory's Human Engineering Division. Each device tests parameters which were selected after examining the performance requirements or expected vision changes associated with the final visual tasks. The evolution of more sophisticated automation used for either the stimulus presentation and the data acquisition is described. The three Visual Function Test instruments include VFT-1, which is currently in several visual functions; the Automated Visual Test System (AVTS), being constructed for the Navy to measure basic aircrew visual functions; and VFT-2, a prototype of one of the tests in an upcoming automated device being constructed for use in detecting drug-induced visual changes.

VFT-1 Development

A little over two years ago, the Air Force Aerospace Medical Research Laboratory (AFAMRL) was invited by both Space Division and the Aerospace Medical Division to propose a number of medical experiments to be conducted aboard DOD and NASA space shuttles. The experimental packages were to investigate areas which were perceived as relatively neglected by NASA, have application to military usage of Man in Space, and meet stringent NASA integration requirements. One of the experiments which was finally accepted and flown by NASA was our Visual Function Tester, Version 1 (VFT-1). The plans for this device have been submitted for patent application as AF Invention No. 15648. A more complete description may be found in AFAMRL TR-84-Ø49.

The VFT-1 (Fig. 1) was designed to test several parameters of human vision, and indicate the changes in these parameters which may be due to the effects of orbital space flight. The system is self-contained, battery operated, and uses microelectronic circuit design techniques to create a series of precisely defined visual stimuli. The entire system weighs less than 1Ø pounds, and is about the size of a cigar box. The test patterns are imaged at or near optical infinity by a relatively simple lens system. Each stimulus area tests a different visual function. The subject looks into the device and sequences through the tests by rotating a multiple position switch located on the right side of the instrument. For two tests, he must press momentary-contact switches located on the top of the instrument. Data are recorded verbally on a continuously operating microcassette audio recorder mounted under the device.

These data are then analyzed at AFAMRL.

Figure 1. Visual Function Tester, Version 1 (VFT-1)

VFT-1 Tests and Rationale

The specific VFT-1 tests were chosen to detect possible changes in neuro-ophthalmological or muscular balance caused by microgravity. Several visual functions are tested; critical fusion frequency, visual acuity (two methods), stereopsis, suppression, heterophorias (all three axes), and eye dominance.

The critical Fusion Frequency (CFF) is that rate at which we perceive a rapidly blinking light as being steady. Evidence exists to indicate that CFF is established by the rate at which neurochemicals can be cycled at synaptic junctions. Much evidence exists to show CFF is an extremely sensitive means of determining our reaction to minimal changes in body chemistry (hypoxia, cigarette smoke, various drugs, etc.). Since the astronauts undergo a change in serum electrolyte balance, we might expect a change in CFF as one of the early objective signs of the physiological effects of this condition.

The CFF test pattern is a 5-degree disk retroilluminated by a yellow flat LED. The LED is driven by a square-wave generator whose frequency is increased by the astronaut by pressing a button. At fusion, the astronaut looks outside the instrument at a 7-segment display. He activates the display to find his CFF, and verbally records the data. The frequency generator is reset, and the test is repeated both for central and peripheral CFF several times.

Changes in visual acuity have been noted by several astronauts. During the early Gemini and Apollo flights, many astronauts commented on their "supervision", or apparent improvement in distant vision acuity while in space. Anecdotal evidence still exists of more recent astronauts "seeing better" at distance and "seeing worse" at nearpoint. Dr. S. Q. Duntley (of Scripps Oceanographic Institute) tested four astronauts' ability to discriminate 4:1 rectangles, both in-cockpit and out the window during the late '60s. He concluded that there was no change in distant visual acuity.

VFT-1 measures two types of visual acuity. One acuity test uses a series of tumbling Es whose angular subtents are graduated in much smaller steps then in similar clinical methods. The second test incorporates a resolution fan whose square-wave pattern gradually increase in spatial frequency. A graduated scale is imaged next to the fan. The astronaut indicates the position of the Es as well as the point at which the individual lines in the fan appear to merge. Ground-based statistical analysis of the responses yields the final visual acuity. Two test plates may be fitted with neutral density filters to determine acuity at mesopic or scotopic light levels, or with contrast-reducing filters to determine acuity at three contrast levels.

Stereopsis may be of extreme importance to astronauts during extravehicular maneuvers, or while controlling their MMU. Although there are at least six visual cues to depth perception, many of them are absent in the textureless visual environment encountered when looking outside a spacecraft. Stereopsis may then be of increased importance to the safety and control of docking, untethered maneuvers, and other nearby operations. Stereopsis requires fine fusional control and a high level of cerebral interpretation of visual data. Under laboratory conditions, some people have displayed stereoacuity as fine as 2 secs of arc. These individuals are able to see a difference in depth between similar objects placed at "infinity" and at 3350 meters.

The stereopsis target in VFT-1 is similar to that in the Armed Forces Vision Test Apparatus, in that one disk of a set of four appears closer than the other three. Several sets of four disks are included. The retinal disparities of the targets in VFT-1 are 80, 70, 60, 50, 30, 22, 16, and 10 secs of arc. The astronaut reads which disk appears closer in each set. A suppression check is included in the stereopsis target.

Each of our eyes is supplied with six extraocular muscles to move our position of gaze throughout a fairly wide angular subtent along three axes of rotation. Fine motor control is needed to coordinate these 12 muscles so the individual lines of sight intersect at the point of regard. The stimuli for movement along one axis of rotation (torsion) involves both vision and gravity. Torsional movements of the eyes can be brought about by tilting the head from side to side, changing both the position of the apparent horizontal and otolith output. The retinal effects of head tilt are partially compensated by a rolling or torquing of the eyes in the opposite direction. If there is a conflict between visual position and otolith-sensed position, it may lead to symptoms of vertigo. VFT-1 measures the "resting state" of eye position for all three axes; horizontal, vertical and torsional.

Lateral (horizontal and vertical) position is indicated by exposing a precision grid to the right eye. Each cell is numbered and lettered both to maintain accommodation control and to indicate the coordinates of the cell. While the astronaut is looking at the grid, a small spot of light in an otherwise dark field is momentarily exposed to the left eye. The astronaut indicates in which cell the spot appears.

Relative torsional position is indicated by exposing two similar circular targets, one to each eye. The right-eye target's circumference contains a series of numbers. The left eye target contains an arrow. When binocularly perceived, the arrow appears to be pointing at or near one of the numbers. The astronaut indicates at which number the arrow points.

The use of Heads-Up Displays (HUDs) and Helmet-Mounted Displays (HMDs) has sensitized us to the importance of binocular vision. If single simultaneous binocular vision is degraded by weightlessness or other conditions, certain haploptically presented visual displays will also be affected. If imagery is presented only to one eye, and different visual information to the other, retinal rivalry will cause only portions of each image to be "seen" at any one time. Typically, the perceived scene shifts back and forth, depending which eye (or field of view) is "dominant" for that moment. One way to test retinal rivalry is to measure the rate at which the eyes trade dominancy, and the duration for which each eye is dominant. VFT-1 presents a different colored/patterned image to each eye. With both eyes open, and while observing the target for approximately 30 secs, the astronaut continually reports which pattern occupies most of his field of view. The audio tape is later analyzed at AFAMRL using Fourier analysis and other techniques to determine both the frequency content and the relative time each eye is "dominant".

Prototype Automated Vision Test System (AVTS)

A second device is being constructed which is almost fully automatic, and whose design should minimize the opportunity to cheat on eye tests. Its purpose is to screen incoming Navy pilot trainees to insure objective and standardized baseline vision testing. Instructions for use are displayed on a liquid crystal display. Either the patient or a medical technician enters the patient's demographic data via a typewriter keyboard. Test stimuli (precision microphotographs) are pseudo-randomly chosen by an onboard microcomputer. Illumination is supplied by light emitting diodes. Data are analyzed internally, and test results are printed out via a dot matrix printer for alter incorporation into the SF88. These results may either be in plain language or encoded for more protection.

Three tests (acuity, stereopsis and phorias) are included, all at optical infinity. In this device, the size and position of the acuity targets (tumbling Es with a "crowding" border) are pseudo-randomly selected by a microcomputer. The patient presses one of four buttons on a response pad to indicate which way the E is oriented. The microcomputer continues to present Es of smaller or larger sizes until a predetermined threshold level has been reached.

Stereopsis is measured with a target similar to that in VFT-1. The patient presses a button corresponding to the closest disk in each group of four. The data are stored in the microcomputer and a threshold stereoacuity is determined.

Horizontal and vertical phorias are also measured with a target similar to that used in VFT-1. The test pattern and the "correct" answer (determined by the microcomputer selecting different positions for the dot as seen by the left eye) is different for each presentation. The patient presses a letter-number combination on the keyboard to indicate the coordinates of a point of light in a test grid. The results are internally stored.

A second-generation AVTS is being planned, which will include tests such as contrast sensitivity, dark focus, dynamic visual acuity, and others. An AFAMRL tech report is in preparation describing the evolution of this device.

Chemical Effects Tests

Depending on the route of administration, many chemical agents, their prophylactics and antidotes can affect the visual system very early in their course of onset. AFAMRL is designing and testing another automated Visual Function Test series which will detect some of these visual changes. The ophthalmic parameters which will be measured with this device include pupillary diameter, contrast threshold, accommodation amplitude and speed as well as CFF and other tests included in other version of the VFT. Investigations are planned to measure changes (if any) in color vision and media-induced haze. Research is ongoing to find predictable changes in visual functions which may be influenced by doses of specific substances. One design goal is to provide an inexpensive field unit for use in forward areas or other locations which are at risk of chemical attack.

One function being investigated is that of contrast threshold. VFT-2 has been completed, which generates variable contract ratio targets of several types: gratings (sine or square wave), resolution fans, "Blackwell Disks", and others. Since the retinal image of a point source of light is not a point but a Gaussian distribution of energy, use of Gaussian disk targets can be helpful in predicting visual performance on both letter type targets (as in clinical visual acuity tests) and real-world targets experienced in daily visual tasks.

It is our hope that automated vision tests, administered more objectively and with specific purposes in mind, will lead to more effective quantification of visual changes brought about by various toxic agents or changes in visual and environment conditions without suffering from excessively subjective influences or errors incurred by relatively untrained personnel.

NAMRL AUTOMATED VISION TESTING DEVICES

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SUMMARY

This laboratory has developed a comprehensive battery of vision testing devices that are being used to measure performance of the visual system in Navy and Marine Corps aircrews. The Automated Vision Test Battery consists of 34 visual acuity/detection tests administered via an automated digital controller system that allows test selection, administration, data collection and storage, and output summary of administered tests. The Dynamic Visual Acuity Test System allows visual acuity measurement of moving targets projected on a circular screen. A digital controller provides for selection of test speed (0 thru + 180 deg/sec), selection of timed stimulus presentation, test administration, and paper printout of trial by trial test data.

AUTOMATED VISION TEST BATTERY

For each of the administered tests, the subject is instructed about test procedures to be followed, such as where to look for fixation and stimulus target, meaning of ready beep, and how to respond to each presented stimulus.

For each of the tests, the first ten trials are considered as practice trials, at the end of which the test is paused to ask the subject if he/she understands the test procedure. If the subject has no questions, testing is continued until all the programmed number of thresholds are obtained, or the maximum number of trials are administered.

At the end of the testing session, test results are stored on a magnetic tape cartridge, and an output summary of test results is printed on paper for the test administrator to evaluate.

Administration of the 34 visual acuity/detection tests of the utomated Vision Test Battery (VTB) is done via a digital controller and the following equipment is interfaced to the controller via an input/output multiprogrammer interface:

1. Six random access slide projectors for precise presentation of stimulus targets.
2. Three non-random access slide projectors for presentation of fixation targets.

3. Ten electronic shutters and drivers for accurate timing of fixation and stimulus pattern presentation.
4. A linear positioning drive mechanism for lateral target movement.
5. A linear adjustable iris drive mechanism for size change (angular rate) of presented stimulus.
6. Subject's response box.

The automated VTB system is best described by its hardware and software configuration.

Hardware Configuration. The hardware configuration of the automated VTB digital controller system, shown in Fig. 1, provides the means to accurately perform the following functions:

1. Power ON or OFF individual projector systems, slide selection of random access projectors (Ø thru 8Ø), and ON/OFF shutter control.
2. Interval timing for accurate control of fixation, and stimulus target presentation as well as collection of the subjects response time.
3. Accurate collection of a subject's response to a given stimulus presentation.

Figures 2 and 3 show a more detailed block diagram of the six projector systems, the linear drive mechanism for target lateral movement, and target size change.

Software Configuration. The software system used to administer the 34 automated VTB tests is composed of a core resident subsystem and non-core resident subsystem. Fig. 4 shows a memory mapping of the software configuration in the HP9825 desktop computer memory.

Core Resident Subsystem. The core resident subsystem is composed of the following subroutines:

1. Input/output subroutines. To allow control of projector systems, and linear drive mechanisms for both target lateral movement and size change.
2. Manual subroutines. To allow projector, slide number, and shutter (fixation or stimulus) selection, as well as a printed status of the projectors.
3. Printout subroutine. To provide a hard copy printout of any test data in memory at the time of its execution.
4. Output summary subroutine. To provide a summarized output analysis of any test data available in memory at the time of its execution.

5. Initial information subroutine. To allow entry and storage of subject's information identification data.
6. Test selection subroutine. To allow selection of any of the 34 visual tests and load the appropriate non-core resident program that is used to administer the selected test.

Non-core resident subsystem. Selection and loading (next to the core resident subsystem) of any of nine non-resident programs is done via the core resident test selection subroutine.

Each of the nine non-core resident programs represent a group of tests of the VTB. The 34 visual tests are grouped as follows:

1. Eight acuity tests.
2. Two lateral detection, acquisition, and identification tests.
3. Four in-depth detection, acquisition, and identification tests.
4. Four lateral movement detection tests.
5. Four spot detection tests.
6. Four spot detection tests (signal detection criteria).
7. Two glare sensitivity acuity test.
8. Two glare sensitivity spot detection tests.
9. Four size change detection tests.

There is an additional non-core resident program that is used for storage of test data on a VTB back-up data cartridge.

Test Design. Each test was designed to consist of ten practice trials, and test trials needed to obtain a given number of thresholds.

With the exception of tests of group 6, all of the threshold measurements were made using an up/down criteria.

For tests measuring acuity resolution, a threshold is defined as the mean value of the gap sizes where a transition from a wrong to a right response occurred.

For tests measuring acuity detection, a threshold is defined as the mean value of the stimulus gap sizes where a transition from a wrong to two consecutive right responses occurred.

For tests measuring exposure time, a threshold is defined as the mean value of the stimulus exposure time where a transition from a wrong to a right response occurred.

Test timing control. Figures 5 thru 10 show timing control diagrams used for each trial presentation of each of the 34 tests.

Test measured variables. Table 1 shows for each group of tests the type of stimulus presented, variables recorded for each test trial and stored on magnetic tape (in addition to the subject's response time in seconds), and final visual performance parameter measured by the tests.

DYNAMIC VISUAL ACUITY TEST

Administration of the Dynamic Visual Acuity test is accomplished by projection of a stimulus target (Landolt C of varying gap size) via a rotating mirror on a 1.22 m radius screen.

The subject is given an acoustical beep to indicate readiness of the test trial and is instructed to report by means of a four-way switch response the gap orientation of the Landolt C stimulus (up, down, right, or left).

Based on the previous trial response, the stimulus target's gap size is increased or decreased prior to the presentation for the next trial.

A threshold can be defined as the mean value of the two gap sizes for which a wrong to right subject response is detected.

The DVA Test is administered via a one-card microprocessor based digital controller system and the following equipment: (1) one random slide projector for precise presentation of the moving stimulus target, (2) constant speed drive control mechanism providing rotation (CW or CCW) of a front surface mirror at the various test speeds (Ø-18Ø deg/sec) for target presentation, (3) one electronic shutter and driver for accurate timing of the stimulus target presentation, and (4) paper printer to provide a hard copy printout of trial by trial test results.

Hardware configuration. The hardware configuration of the DVA digital controller system is shown in Fig. 11.

The Prolog 8Ø85 microprocessor based one-card microcomputer houses the EPROM (8K) software configuration (firmware) as well as the RAM (2K) needed for execution of the software system programs, and temporary test data storage.

Interfacing of the 8Ø85 microprocessor based controller with input/output peripherals is done through three output ports and two input ports.

Software configuration. The software system of the DVA digital controller system was designed as a group of subroutines to perform the following tasks:

(a) Automatic testing of the digital controller itself, as well as all the interfaced peripherals.

(b) Manual control (from the keyboard) of projector function (ON/OFF), selection of slide number (Ø-8Ø), and shutter control (ON/OFF).

(c) Manual control of speed selection and direction of rotating drive subsystem (mirror control).

(d) Test administration, trial by trial data collection and printout.

Prior to administering the DVA test, the software system allows for keyboard entry of the following test parameters:

(1) Test speed (degrees/sec) selection.

(2) Stimulus time presentation (sec) selection.

(3) Number of thresholds (using the up/down method) for which the test is to be administered (maximum of 8Ø test trials).

Test administration starts with ten practice trials used to insure that the proper slide tray is selected, and that the subject is familiarized with test procedure. After practice trials are over and the subject is ready, testing continues until the number of selected thresholds have been completed.

At the end of the test, the digital controller prints out the trial by trial test results, followed by a printout of the slide number (for each threshold) for which the subject gave a right response followed by a previous wrong response. This slide number is then used to read the value of DVA threshold from a look-up table according to the tray of Landolt C's used.

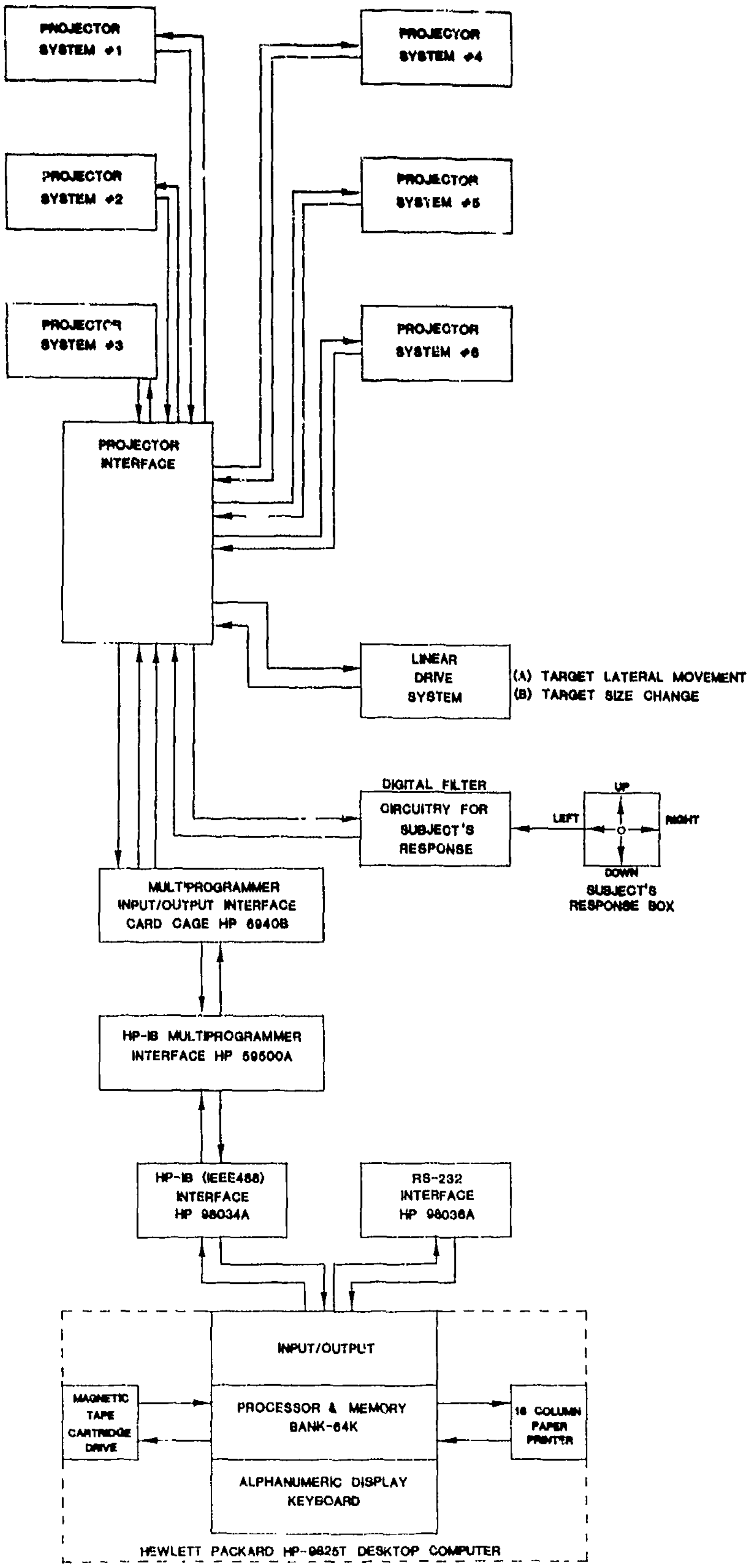


FIGURE 1. DIGITAL SYSTEM CONTROLLER BLOCK DIAGRAM

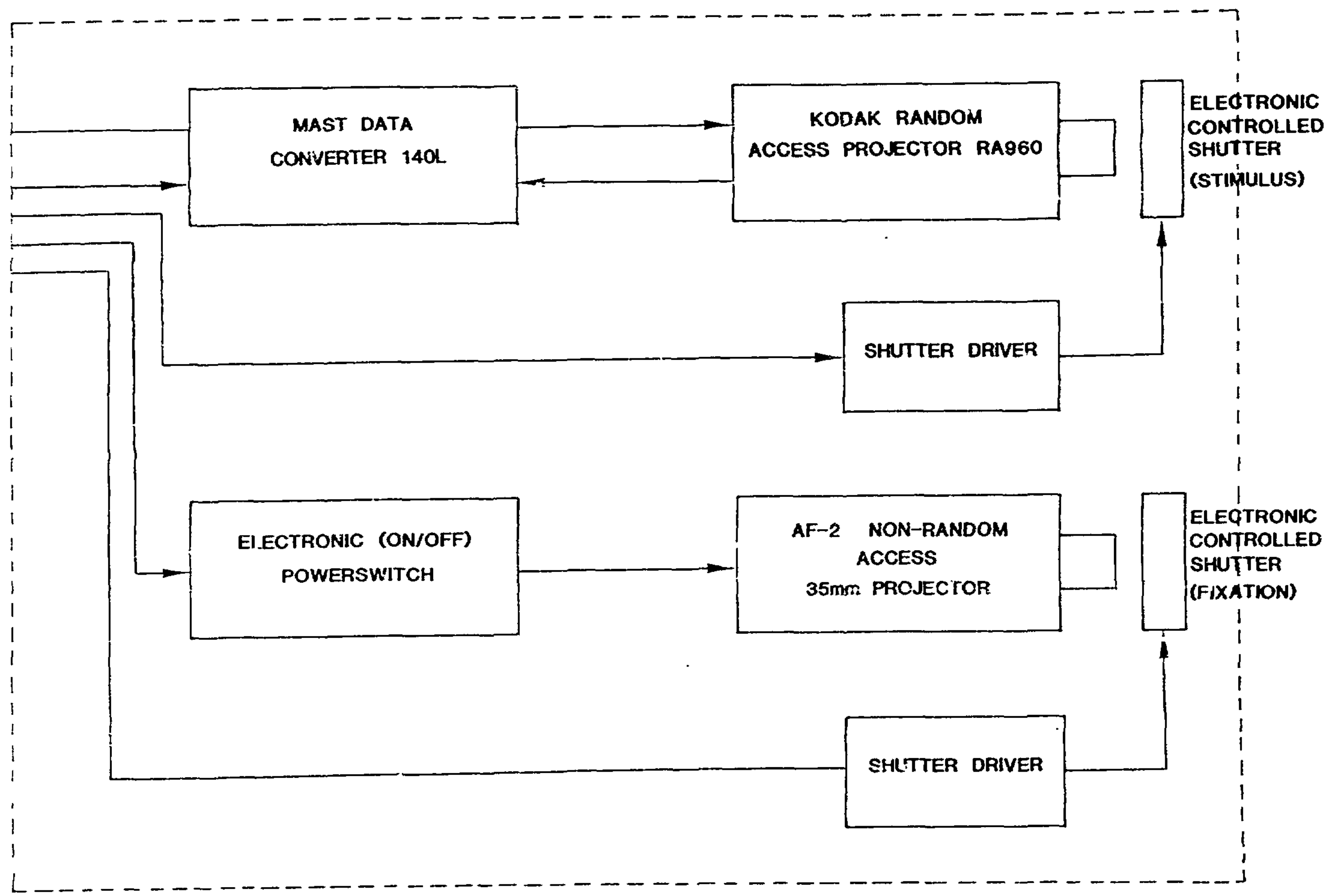


FIGURE 2. PROJECTOR SYSTEM BLOCK DIAGRAM

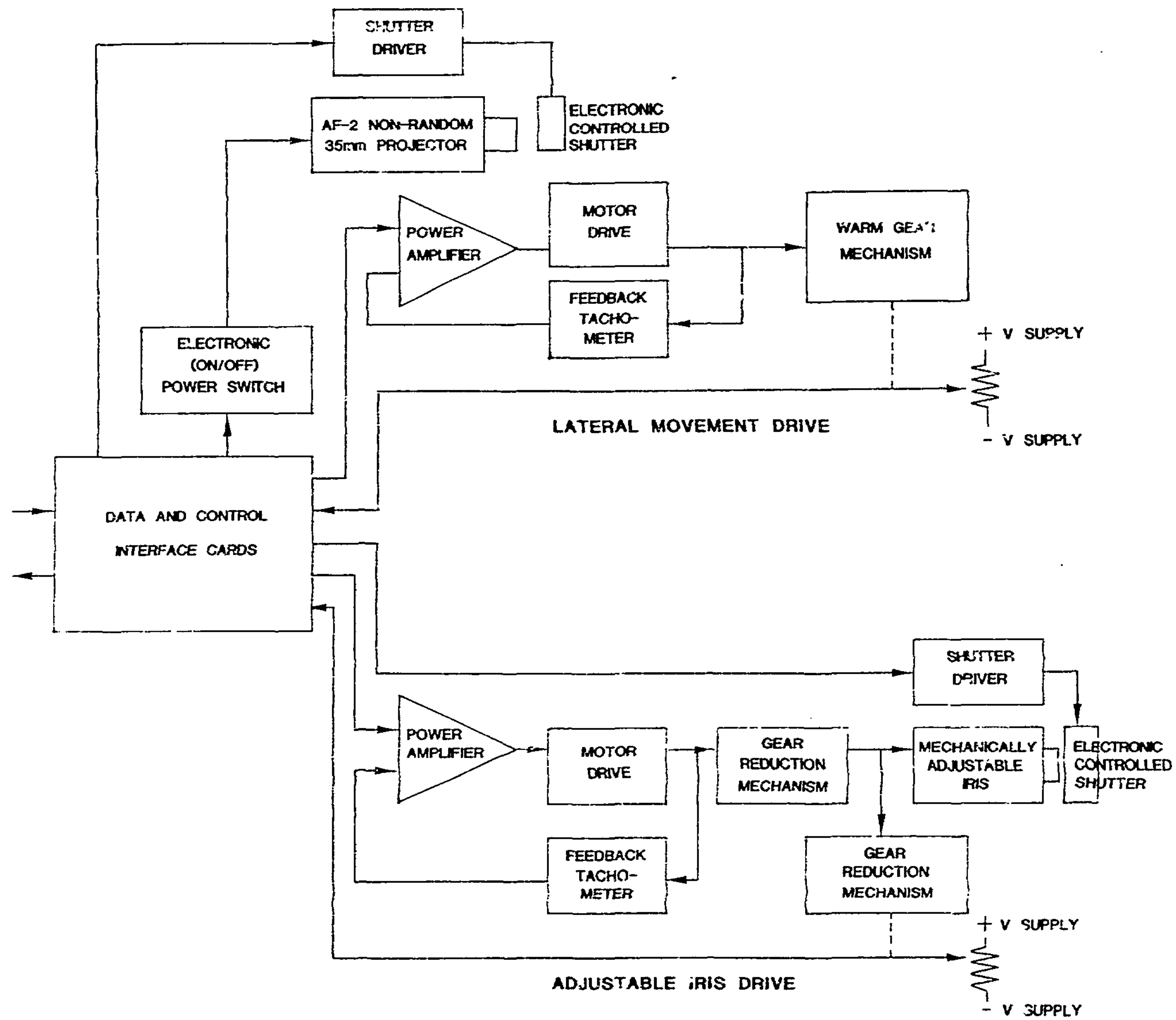


FIGURE 3. LINEAR DRIVE SYSTEM - BLOCK DIAGRAM
(A) TARGET LATERAL MOVEMENT
(B) TARGET SIZE CHANGE

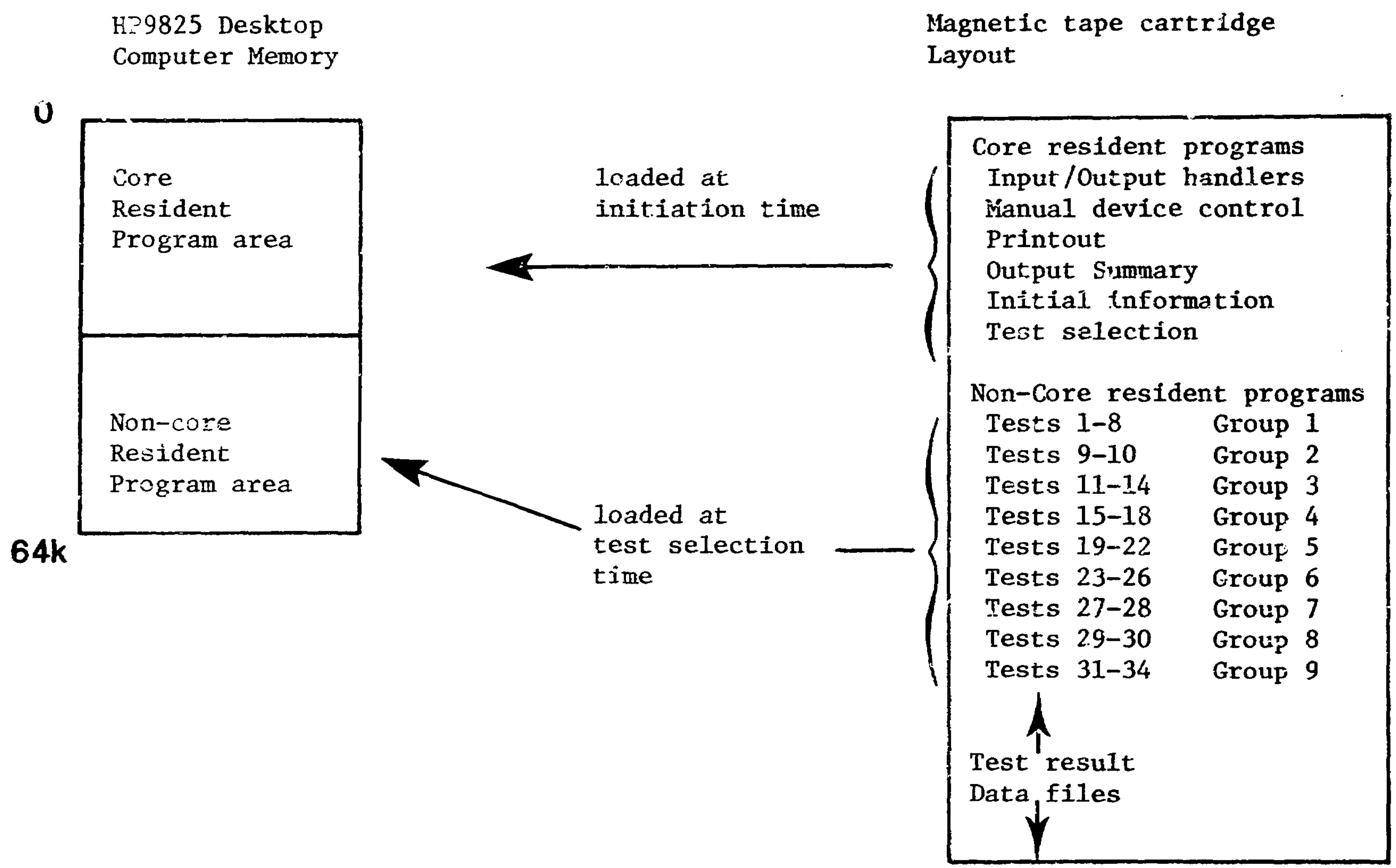
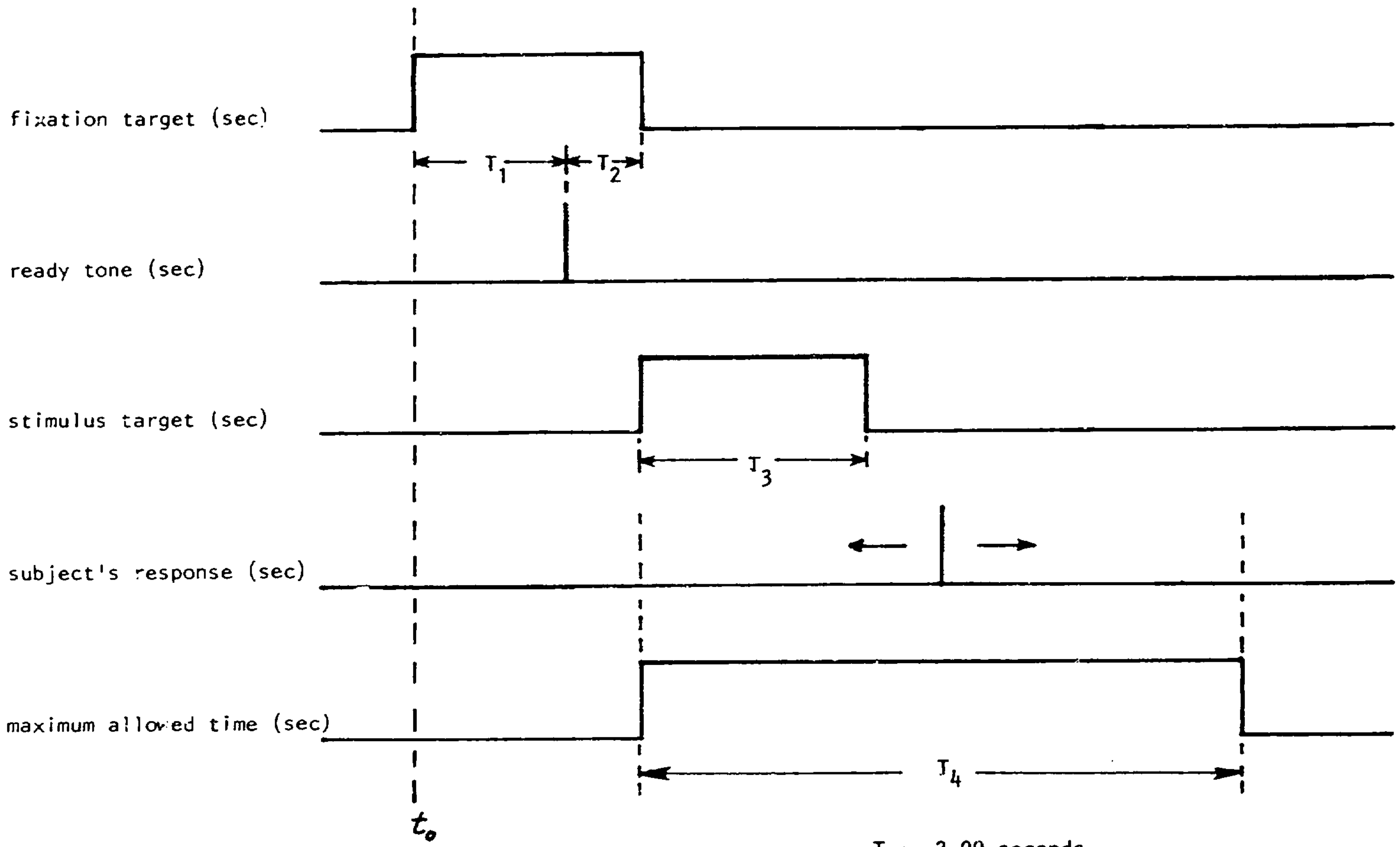


Figure 4. Software Configuration Memory Mapping

VTB Tests 1-8: ACUITY FAR/NEAR, CENTRAL/PERIPHERAL, HIGH/LOW CONTRAST

Time Lines



T_1: 2.00 seconds

T_2: 1.00 seconds

T_3: 3.00 seconds

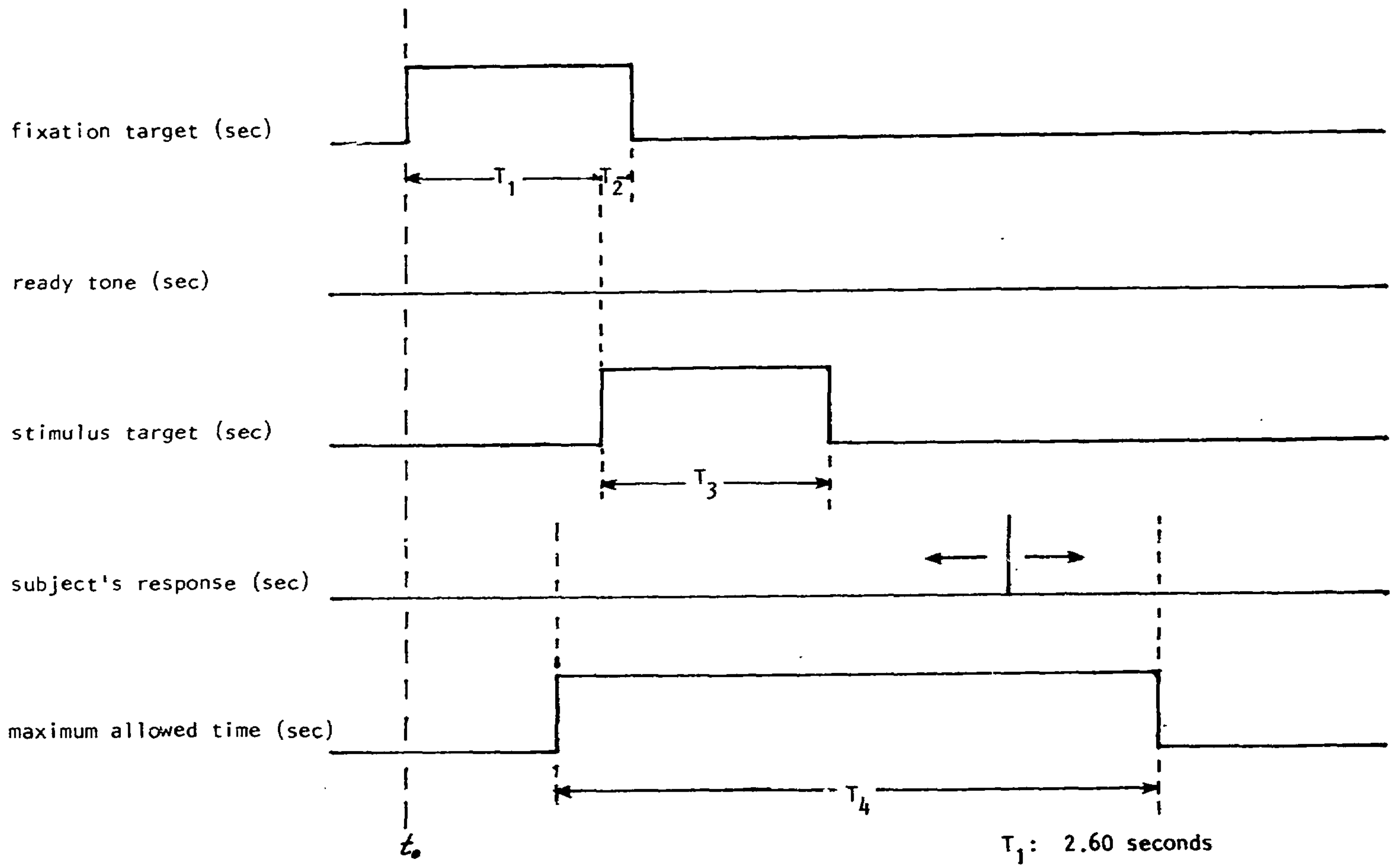
T_4: 8.00 seconds

T_5: 3.00 seconds (inter trial interval)

Figure 5. SINGLE TRIAL TIMING

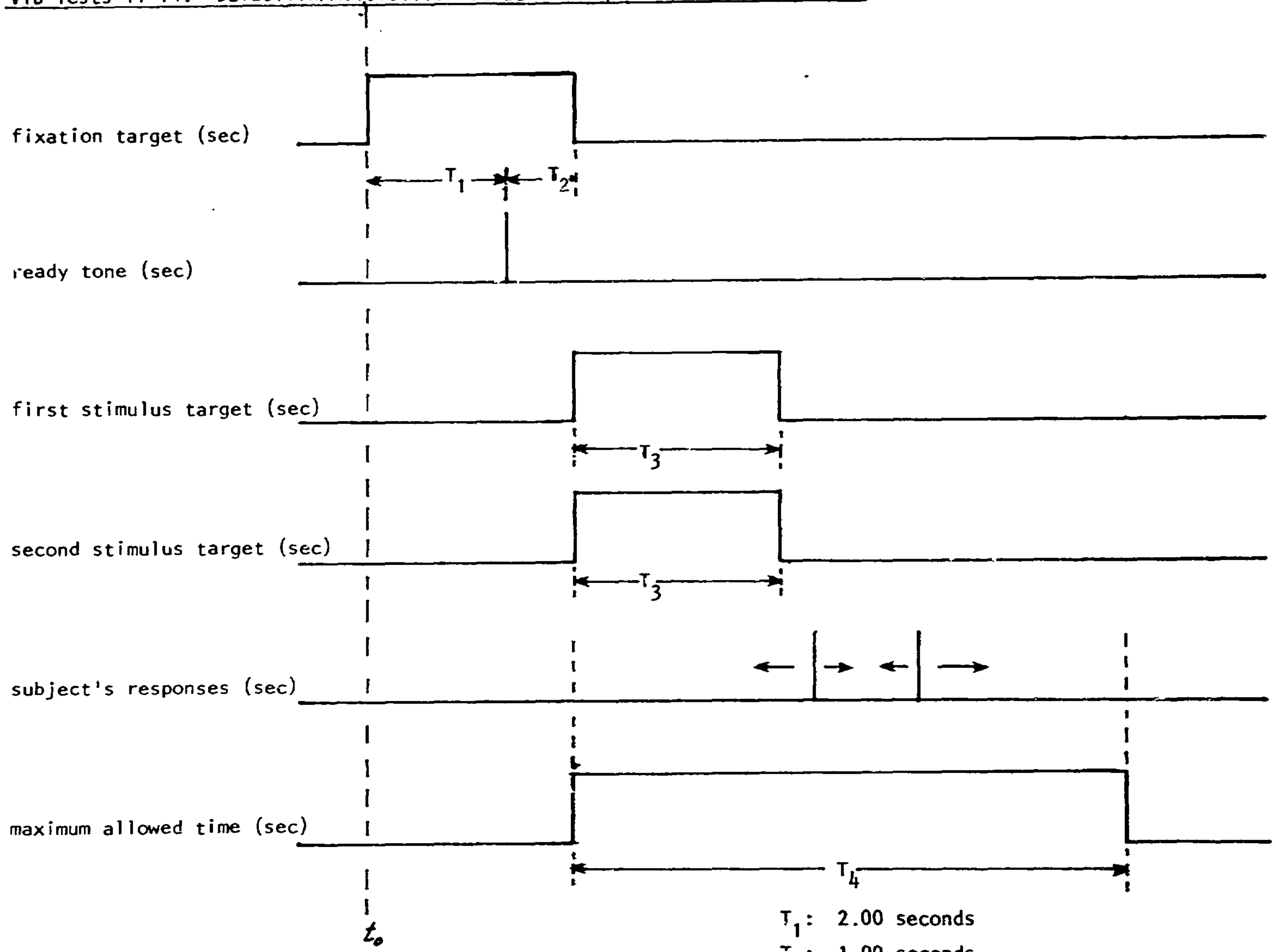
VTB Tests 9-10: LATERAL DETECTION ACQUISITION FAR HIGH/LOW CONTRAST

Time Lines



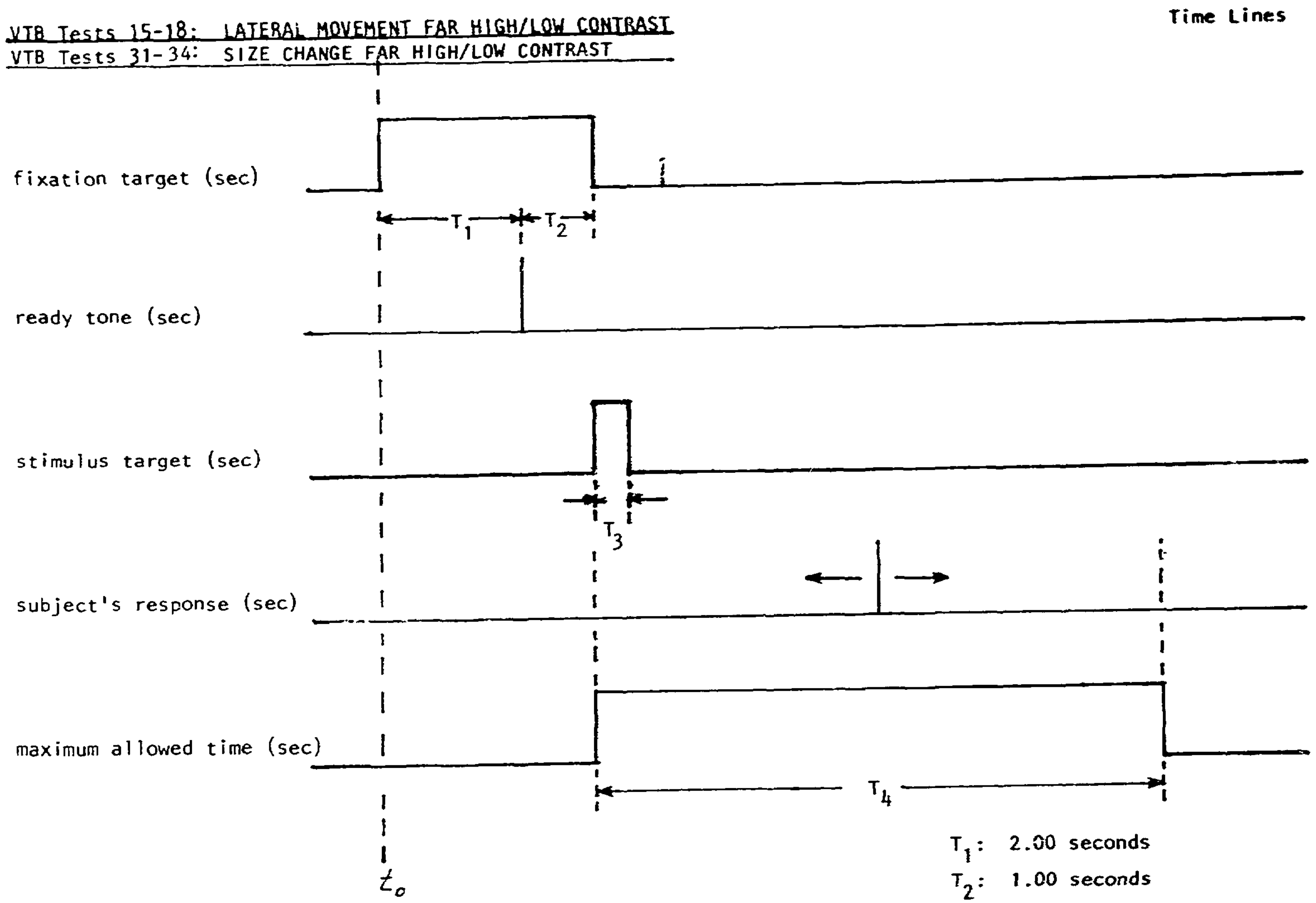
T_1: 2.60 seconds
T_2: 0.40 seconds
T_3: 3.00 seconds
T_4: 8.00 seconds
T_5: 3.00 seconds (inter trial interval)

Figure 6. SINGLE TRIAL TIMING



T_1: 2.00 seconds
T_2: 1.00 seconds
T_3: 3.00 seconds
T_4: 8.00 seconds
T_5: 3.00 seconds (inter trial interval)

Figure 7. SINGLE TRIAL TIMING



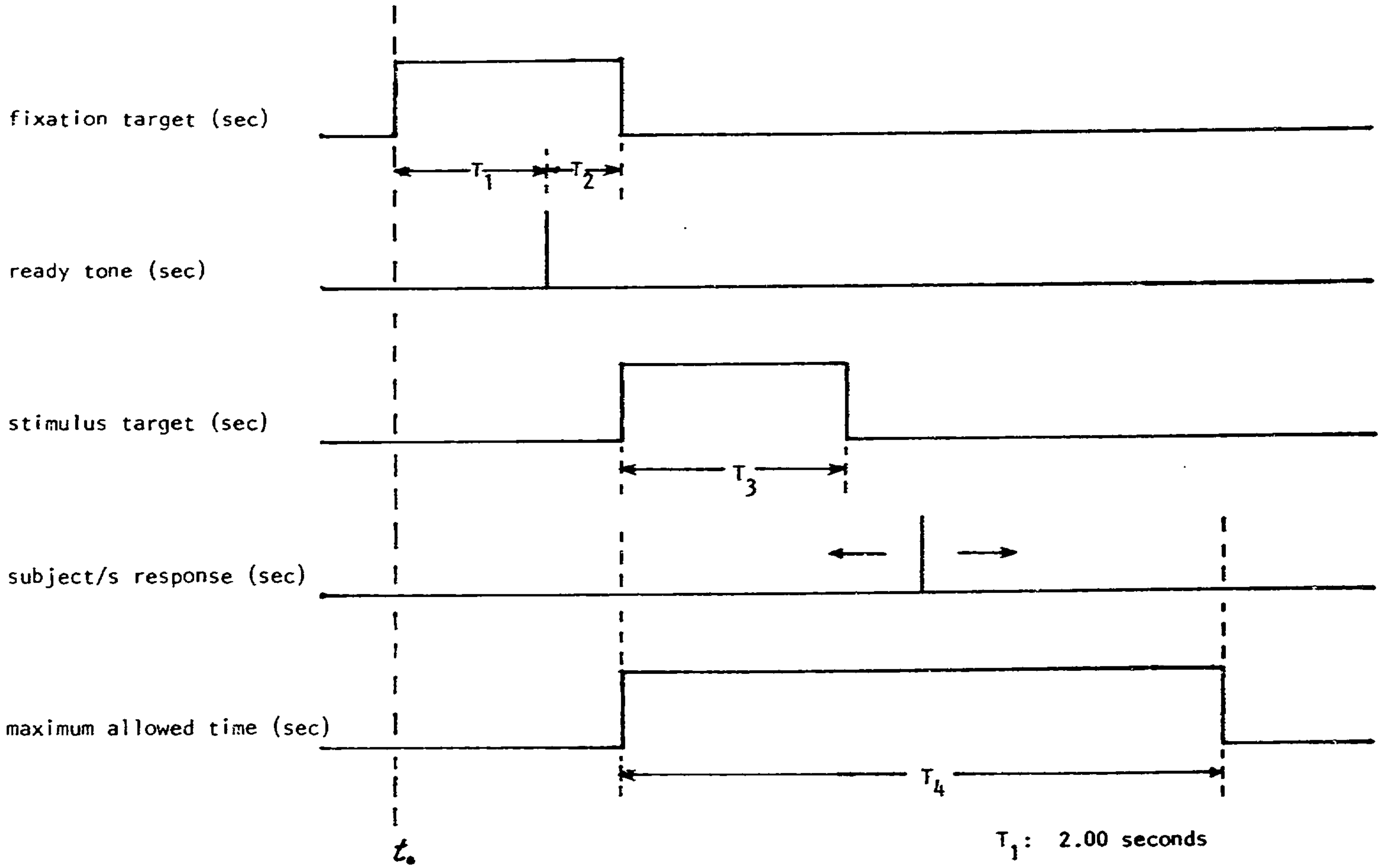
T_1: 2.00 seconds
T_2: 1.00 seconds
T_3: 0.50 seconds
T_4: 8.00 seconds
T_5: 3.00 seconds (inter trial interval)

NOTE 1: Fixation target off and stimulus target on set by Unislide passing thru HOME position.

Figure 8. SINGLE TRIAL TIMING

VTB Tests 19-22 & 23-26: CENTRAL/PERIPHERAL SPOT DETECTION FAR HIGH/LOW CONTRAST

Time Lines



T_1: 2.00 seconds
T_2: 1.00 seconds
T_3: 3.00 seconds
T_4: 8.00 seconds
T_5: 3.00 seconds (inter trial interval)

Figure 9. SINGLE TRIAL TIMING

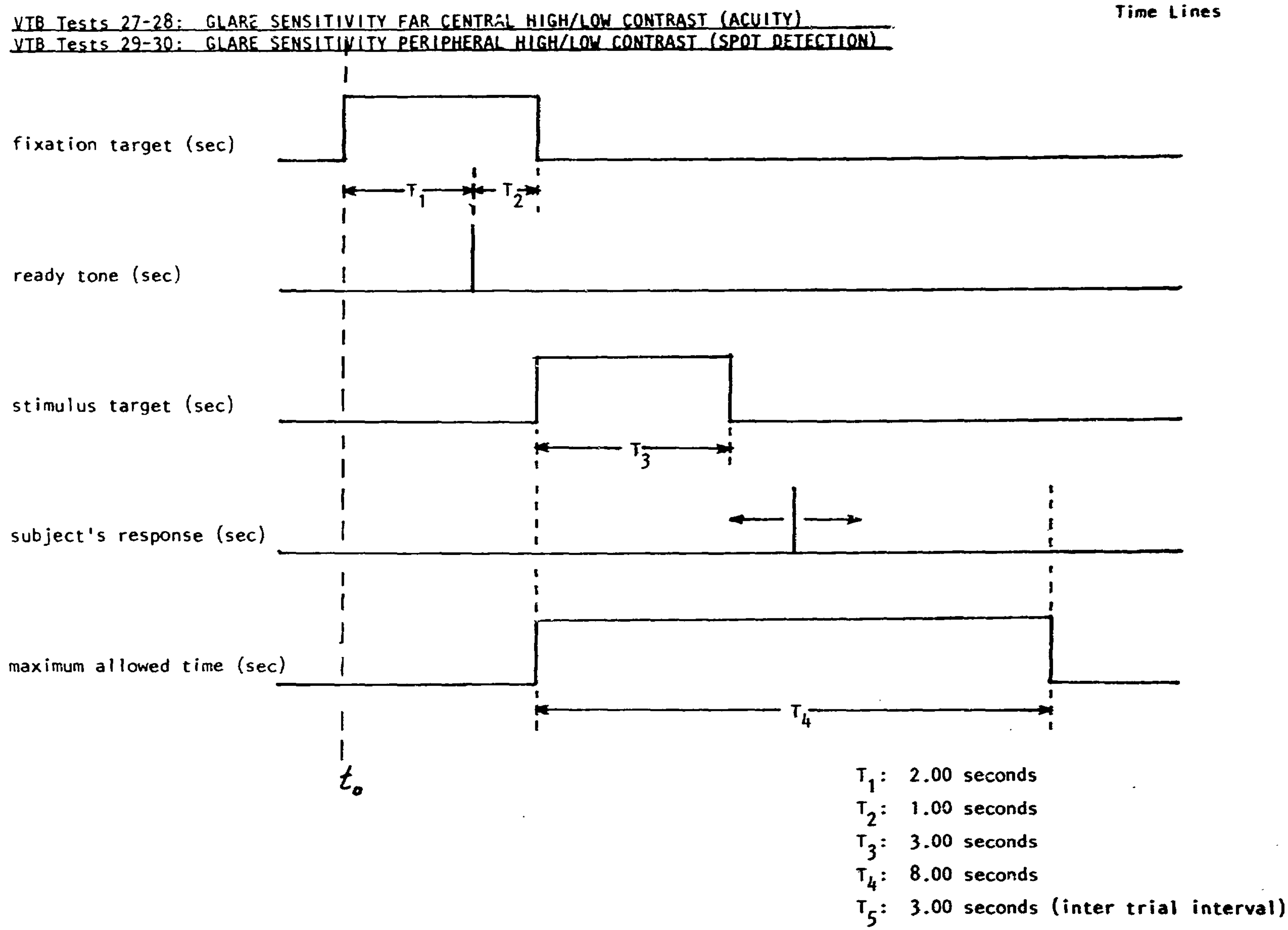


Figure 10. SINGLE TRIAL TIMING

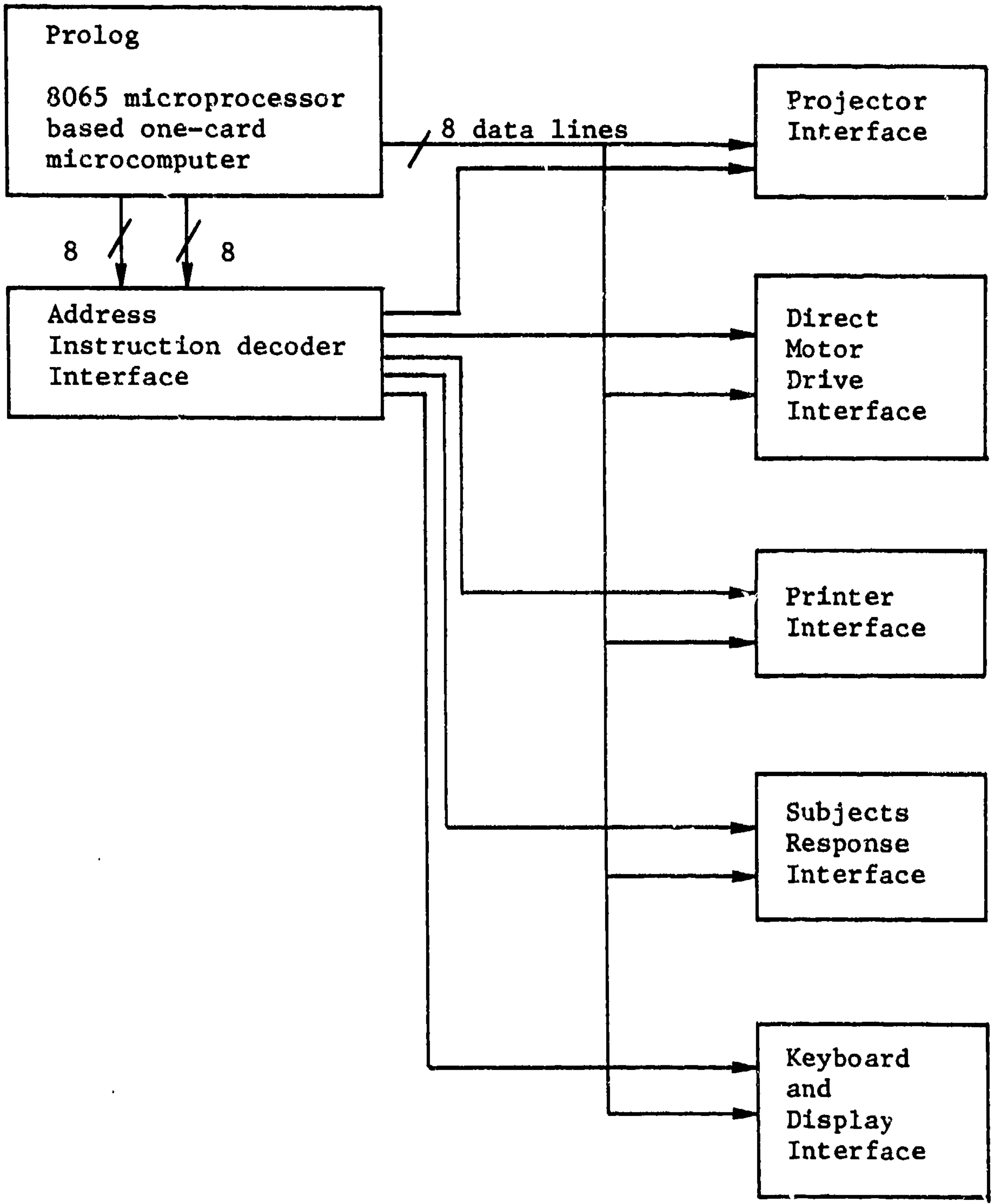


Figure 11. DVA Digital Controller Hardware Configuration

Table 1. TEST MEASURED VARIABLES, STIMULUS USED, TEST MEASURE

Test Group	Stimulus Presented	Variables Stored and Recorded	Test Measure
1 Tests 1-8	Landolt C varying GAP Size Random Orientation (Four Possibilities)	Stimulus GAP Size Orientation Presented Responded	Acuity - Resolution Threshold in Minutes of Arc (MARC)
2 Tests 9-10	Same as for Group 1	Same as for Group 1	Acuity - Detection Threshold in MARC Acuity - Resolution Threshold in MARC
3 Tests 11-14	Landolt C Fixed GAP Size Random Orientation (Four Possibilities)	Stimulus Exposure Time Orientation Presented Responded	Stimulus Exposure Time Threshold in Seconds
4 Tests 15-18	Fixed Size Spot Varying Speed in MARC/SEC Random Lateral Movement (Right/Left)	Spot Velocity Direction of Movement Presented Responded	Spot Velocity - Detection Threshold Right Movements - MARC/SEC Spot Velocity - Detection Threshold Left Movements - MARC/SEC
5 Tests 19-22	Spot Varying Size	Spot Size Spot Presented Spot Detected	Acuity - Detection Threshold in MARC
6 Tests 23-26	Spot Fixed Size	Number of Hits Number of Misses False Alarms/Correct Rejections	D prime Beta Signal Detection Analysis
7 Tests 27-28	Glare Landolt C varying GAP Size Random Orientation (Four Possibilities)	Same as for Group 1	Same as for Group 1
8 Tests 29-30	Glare Spot Varying Size	Same as for Group 5	Same as for Group 5
9 Tests 31-34	Spot Varying Size Random Direction of Size Change (Growing/ Shrinking	Spot Rate of Size Change Direction of Change Presented Responded	Spot Rate of Size Change - Detection Threshold - Increase/ Decrease MARC/Sec

AUTOMATED VISUAL FIELD TESTING

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SUMMARY

Automated visual field testing has become a valuable clinical diagnostic tool for detecting, quantitatively evaluating, and monitoring the status of ophthalmic and associated neurologic disorders. Recently, it has also been used for screening large populations to examine the relationships between peripheral visual function and task performance. This paper provides a brief overview of the various uses of automated visual field testing and the strategies, instrumentation and test conditions employed for specific applications. The capabilities and limitations of automated visual field testing for screening, quantitative measurement and classification of peripheral visual function are described. Future advances in automated visual field testing should include more efficient and accurate decision-making test strategies for quantitative evaluation, as well as the development of low-cost, rapid screening devices for distinguishing between normal and abnormal peripheral visual function.

INTRODUCTION

Twelve years ago, Fankhauser and Koch (1) published a theoretical analysis of test strategies, patient characteristics and other factors that were important to the development of an automated visual field test device. From this beginning, automated perimetry and visual field testing have undergone technological advances and growth that parallel the microcomputer industry. Today, more than 25 different types of automated perimeters are available from various manufacturers, (2) eight or more other automated perimeters have come and gone since 1976, and nearly 200 clinical comparison studies and other research papers have been published about automated perimetry (2-11).

Automated visual field testing has been used for several purposes: (1) screening for ocular and neurological pathology in clinical populations, (2) quantitative measurement and monitoring of visual field status in clinical populations, (3) screening large groups of the general population to determine the prevalence of ocular and neurologic disorders, and (4) evaluation of the relationship between visual field status and task performance. An abundance of studies have reported that automated perimetry can successfully be used for all of these purposes, provided that proper test conditions and strategies are employed (see bibliographies in references 2-4 for comprehensive listings of published automated perimetry studies). Two basic test procedures have been used for automated perimetry (5); one of them is most appropriate for screening, while the other is most useful for quantitative measurement of visual field sensitivity. While the present paper will briefly describe both forms of testing, particular emphasis will be placed on screening procedures because of their relevance to selection, retention and classification considerations for military personnel.

AUTOMATED PERIMETRY TEST STRATEGIES

Screening strategies for automated perimetry utilize a technique known as suprathreshold static perimetry. Targets are presented in a random order at predetermined locations in the visual field. Stimulus luminances are adjusted to values that are assumed to be above normal threshold levels ("suprathreshold"), thereby making them easily detectable for visual field locations with normal sensitivity characteristics. Several strategies for establishing normal suprathreshold stimulus luminances have been developed (4,5). The observer's task is to indicate each time a target is detected, and the automated device maintains a record of which target locations were seen and which were not seen. Since suprathreshold static perimetry is intended for screening and limited quantitative assessment of the visual field, the target presentation patterns are usually designed to optimize detection of visual field abnormalities. Thus, targets are placed at strategic locations that are most frequently associated with visual field defects produced by glaucoma, retinal disease, optic nerve disease, chiasmal and post-chiasmal disorders, as well as other common visual problems that affect peripheral vision. The use of optimal target presentation patterns, test strategies, error-checking procedures and standardized criteria for data interpretation can produce detection rates as high as 95% and false positive rates as low as 4% (4,6,7). In addition, a recent study by Ford et al. (8) suggests that automated visual field screening is a more sensitive method of screening for glaucoma than either optic disc evaluation or tonometry. As a quantitative screening method, suprathreshold static perimetry is an effective means of determining visual field abnormalities produced by ocular and neurologic disorders.

Static perimetry is used by automated devices to provide full quantitative information about the sensitivity of visual field locations. The basic strategy for automated static perimetry consists of determining the minimum or threshold luminance necessary to detect the presence of a target whose location and size remain constant. Measurements of the luminance detection thresholds for a number of visual field locations thereby generate a mapping of the overall sensitivity characteristics of the visual field. Most of the automated devices that employ static threshold testing use a staircase or bracketing technique to establish detection thresholds. The target luminance is initially adjusted to be slightly above or below the presumed detection threshold for a particular visual field location. If the target is seen, the luminance is decreased for the next presentation; if the target is not seen, the luminance is increased for the next presentation. After a specified number of staircase "reversals" (seeing to non-seeing and vice versa) the average stimulus luminance (the luminance midway between reversals) is determined as the detection threshold. Typically, automated perimeters perform a pseudo-random presentation order of target location and stimulus luminance combinations. The target presentation pattern is usually symmetric (either a cartesian coordinate grid or a polar coordinate radial pattern). This may have a slight disadvantage for detection of small defects, but has a distinct advantage for data representation purposes. Symmetric patterns make data interpolation and smoothing functions much simpler, thereby allowing automated perimeters to present topographic representations of visual field sensitivity through the use of such procedures. The most popular type of representation is one which uses a grey scale mapping routine for different luminance threshold levels. A areas of high sensitivity are depicted with a light shading; areas of low sensitivity are represented by a dark shading; and moderate sensitivity regions are shown by intermediate levels of shading. The better versions of automated static perimetry can perform as well as or better than highly-skilled perimetric techinicians using the most sensitive manual techniques. Detection rates of 95 to 100% and false alarm rates of 3 to 10% have been reported for automated threshold static perimetry (2,9,10). In addition, this form of testing provides accurate measurements of visual field sensitivity that are useful for specifying the amount of visual loss in regions of abnormal sensitivity, and for monitoring the visual status of patients with glaucoma and other eye diseases. For some devices, statistical comparsions can be made between different exam results, or between the results of a single exam and normal population values. These innovations have provided a new, unique set of diagnostic tools for the clinician.

MASS VISUAL FIELD SCREENING

Rapid screening of visual fields in large populations is important for early detection of ocular and neurologic disorders, and for identifying peripheral vision loss that may impair the performance of visually-dependent tasks. Driving, orientation and mobility tasks, and other related skills have been reported to show significant performance decrements when there is a significant amount of visual field loss (11-13). Often, this degraded performance occurs even when central visual acuity is minimally affected, and when the individual is not directly aware of the peripheral deficit.

Recently, we performed a mass visual field screening of 10,000 California driver's license applicants (20,000 eyes) (11). The most important findings of our study can be summarized as follows: (1) the prevalence of visual field loss was 3 to 3.5% between the ages of 16 and 60, 6% for ages 61 to 65, and 13% for those over age 65; (2) one-third of the individuals with peripheral visual field loss had deficits in both eyes; (3) 57% of the individuals with peripheral visual field loss were previously unaware of any vision problem; (4) the three most common factors responsible for peripheral visual field loss (as determined by follow-up studies) included cataracts, glaucoma and various retinal disorders; (5) individuals with visual field deficits in both eyes had accident and conviction rates that were more than double those of their age- and sex-matched control group with normal visual fields, a statistically significant difference; (6) individuals with visual field loss in only one eye had no difference in accident and conviction rates as compared to their age- and sex-matched control group with normal visual fields.

Similar decrements in driving performance have been reported in several other recent studies (12,13). These findings point out three important issues. First, visual field loss can result in degraded task performance, especially when components of the task require good spatial localization, visual orientation, or mobility skills. Second, it is essential to perform perimetric screening tests to accurately identify visual field loss, since more than half of the individuals with such deficits in our study were unaware of any vision problem. Similar findings have been reported in a mass visual field screening study conducted in Sweden (14). Third, mass visual field screening can be performed on large populations in an effective and efficient manner. In our study (11), less than 2 min per eye were required for testing (including set-up and alignment time), with more than 100 individuals being tested on a single device during some examination days.

Automated visual field testing has many advantages over manual perimetry, especially for screening purposes. Perhaps the most important benefit is the ability to use standardized test conditions and evaluation strategies. This minimizes the variability in testing that is due to the procedure itself, and permits a more accurate means of developing population norms. Automated perimetry does not require a highly-skilled perimetric technician to perform the test, which is another distinct advantage over manual perimetry. Although some type of supervision is needed for aligning the observer, initiating the test and other related activities, these tasks require minimal training. In our mass visual field screening study, two clerical workers were trained for one hour and supervised for two hours prior to conducting all visual field tests in 10,000 individuals. Some of the more sophisticated automated perimeters may require from one to three days of training and supervision for technicians to become fully accustomed to the device, but this compares favorably with the three to six months that it takes us to fully train a technician to perform reliable, accurate manual perimetry. Other advantages offered by many of the current automated perimeters include: greater time and cost efficiency for performing visual field testing; reliable monitoring of eye position during testing; ability to store, retrieve and quantitatively compare test results to normal age-related population characteristics; and the ability to present the test results according to several graphical representation schemes. Several devices have released new test procedures which provide the benefit of combining screening and quantitative threshold evaluations. These strategies begin testing with a rapid screening procedure. If the observer's responses are consistent with normal age-related population characteristics, no further testing is performed. However, those locations which have responses that suggest lower than normal sensitivity are then tested with a full quantitative evaluation strategy. For clinical purposes, this type of test procedure represents a significant advantage in test time.

Clearly, automated perimetry is not a total panacea for visual field testing. Several problems and disadvantages are still prevalent in automated perimetry, despite significant advances within the last five years. Manual perimetry is still more flexible and adaptive than automated perimetry, an important factor for observers who are uncooperative, inattentive or otherwise difficult to test. Another problem associated with automated perimetry concerns the interpretation of test results. Automated visual field testing not only uses test procedures that are different from manual perimetry, but also has graphic representations of test results that are substantially different from those traditionally uses for manual testing. These unfamiliar visual field representations, combined with the more sensitive test procedures (which are able to detect very subtle, early deficits that are difficult to distinguish from normal variations in sensitivity), have produced a significant interpretation problem for many practitioners. This difficulty is compounded by the fact that each of the commercially-available devices uses different test conditions (e.g., background luminance, target size, stimulus duration), test strategies and data representation methods. There is a growing need for the development of industry standards or guidelines for various aspects of automated visual field testing, much like the computer industry's establishment of standards for interfaces, communications protocols and similar factors.

FUTURE DEVELOPMENT OF AUTOMATED PERIMETRY

Automated perimetry is now a widely-accepted method of performing quantitative visual field testing for clinical purposes. Current research has also shown that it can be used effectively to screen large populations to detect visual disorders or to screen for peripheral vision loss that may degrade performance of certain tasks. In general, future advances in automated perimetry should be directed towards the establishment of standard, easy-to-interpret data representation schemes, and the development of more accurate and efficient test strategies. At the present time, most test strategies either perform a fixed test procedure, or they conduct a *post hoc* evaluation of test results for error-checking, refinement of data, and other procedures to enhance the reliability of the procedure. The development of heuristic, adaptive strategies that can evaluate the quality, accuracy and consistency of the data as it is being acquired, and modify the procedure accordingly, would provide an important advancement in automated visual field testing.

With regard to screening large populations, there is a significant need for a low cost, commercially-available visual field screening device. At the present time, automated perimeters that are capable of testing the full peripheral visual field cost $6,000 or more. This cost is a prohibitive factor for many organizations that might otherwise wish to perform visual field screening. Many of the features and test options on these automated perimeters are not necessary for rapid screening, and could be eliminated. We feel that a high quality visual field screening device could be developed for under $1,000, and that this price range may make it feasible for such testing to be performed on a large scale basis by groups interested in evaluating peripheral visual function in large populations.

REFERENCES

1. Fankhauser, F. and Koch, P. 1972. On automation of perimetry. Graefes Arch. Clin. Exp. Ophthalmol. 184:126-150.

2. Keltner, J. L. and Johnson, C. A. 1984. Comparative material on automated and semiautomated perimeters - 1984. Ophthalmology Instrument and Book Supplement, pp. 27-50.

3. *Perimeter Digest*, Switzerland: Interzeag, 1983.

4. Keltner, J. L. and Johnson, C. A. 1983. Screening for visual field abnormalities with automated perimetry. Surv. Ophthalmol. 28:175-183.

5. Johnson, C. A. 1983. The test logic of automated perimetry. Acta XXIV Intl. Cong. of Ophthal., Philadelphia, Lippincott, pp. 151-155.

6. Keltner, J. L. and Johnson, C. A. 1984. Automated and manual perimetry - A six year overview. Ophthalmol. 91:68-85.

7. Johnson, C. A. and Keltner, J. L. 1980. Automated supra-threshold static perimetry. Am. J. Ophthalmol. 89:731-741.

8. Ford, V. J., Zimmerman, T. J. and Kooner, K. 1982. A comparison of screening methods for the detection of glaucoma. Invest. Ophthalmol. Vis. Sci. (Suppl.) 22:257.

9. Fankhauser, F., Spahr, J. and Bebie, H. 1977. Three years of experience with the OCTOPUS automated perimeter. Doc. Ophthalmol. Proceedings Ser. 17:7-15.

10. Heijl, A. and Drance, S. M. 1981. A clinical comparison of three computerized automatic perimeters in the detection of glaucoma defects. Arch. Ophthalmol. 99:832-836.

11. Johnson, C. A. and Keltner, J. L. 1983. The incidence of visual field loss in 20,000 eyes and its relationship to driving performance. Arch. Ophthalmol. 101:371-375.

12. Fishman, G. A., Anderson, R. J., Stinson, and L., Haque, A. 1981. Driving performance of retinitis pigmentosa patients. Br. J. Ophthalmol. 65:122-126.

13. Verriest,G., Bailey, I., Calabria, G., Campos, E., Crick, R., Enoch, J., Esterman, B., Friedmann, A., Ikeda, M., Johnson, C., Overington, I., Ronchi, L., Saida, S., Serra, A., Villani, S., Weale, R., Wolbarsht, M. and Zingirian, M. 1984. The occupational visual field II. Practical aspects: The functional visual field in abnormal conditions and its relationship to visual ergonomics, visual impairment and job fitness. Doc. Ophthalmol. Proc. Ser. (In press.)

14. Bengtsson, B. and Krakau, C.E.T. 1979. Automatic perimetry in a population survey. Acta Ophthalmol. 57:929-937.

THE COMMITTEE ON VISION: A BRIDGE BETWEEN BASIC AND APPLIED SCIENCE

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SUMMARY

The Committee on Vision is the primary instrument of the National Academy of Sciences for providing analysis and advice on issues related to vision. The committee also provides a forum for relating basic science information to applied visual problems, and it endeavors to further the development of visual science. Through its working groups, the committee deals with a range of questions involving engineering and equipment, physiological and physical optics, visual neurophysiology, psychophysics, perception, environmental effects on vision, and treatment of visual disorders. This article describes ways in which the committee assists requesting agencies and the vision research community.

BACKGROUND

The history of the Committee on Vision extends over more than thirty-five years of continuous activity. It was constituted in early 1944, as the Armed Forces Vision Committee, to provide advice on urgent problems involving vision faced by the Allied Forces in WW II. The success of the Committee in applying science to a range of applied problems led to its present status as the National Research Council Committee on Vision. At present, the committee is sponsored on a continuing basis by the Departments of the Army, Navy, and Air Force, the National Aeronautics and Space Administration, the National Science Foundation, the National Institute of Handicapped Research, the National Institute on Aging, the Office of Special Education, the Veterans Administration, the American Academy of Ophthalmology and the American Optometric Association. Each of these agencies contributes a fixed sum yearly, through a consortium contract administered by the Office of Naval Research. In addition, agencies may contract with the National Academy of Sciences for specific studies performed by the committee.

Because of its unique history and composition, the committee provides a mechanism through which scientific and technical personnel in structurally separate agencies can be brought together to deal with common problems. In addition to being able to tap a wide range of technical expertise, the committee has established ties with a variety of government, educational and private organizations. It has worked in cooperation with other branches of the National Research Council: the Commission of Life Sciences, the Institute of Medicine, and the Transportation Research Board. The committee, is thus, in a strategic position to relate vision to human problems and social issues by:

> Applying scientific and technical knowledge to the solution of problems involving vision.
>
> Planning research to meet anticipated problems.

Bringing problems that concern requesting agencies to the attention of the scientific community.

Promoting the exchange of research information.

Identifying deficiencies in scientific knowledge and encouraging research designed to reduce them.

Encouraging and facilitating communications among basic and applied scientists in this country and abroad.

COMMITTEE ORGANIZATION

Members of the committee are selected from the community of vision scientists at large and appointed by the National Research Council to serve three year terms. In addition, each continuing sponsor appoints a scientific representative. Individuals are selected on the basis of their scientific stature, their interest in applying visual science to applied and human problems, and their willingness to commit the time required for committee participation. Since the work of the committee cuts across many discipline lines, its membership includes broad expertise in biology, behavioral and social sciences, physics, engineering, and medicine. Committee members act as a steering group that provides overall policy supervision of committee and sponsor representatives.

Until 1979, the committee designated "associate members" and "foreign correspondents." These designations were terminated in order to streamline the committee organization. At the same time, the individuals who had held these titles became the core of a master mailing list that was designed to broaden direct communication channels between sponsoring agencies and the vision research community. Individuals on the master mailing list receive an annual newsletter and announcements of all committee publications. The mailing list provides a pool of experts who are familiar with committee operations and who can offer advice on a wide range of science and technology.

Responsibility for the general management of committee business rests with the study director, with offices at the National Academy of Sciences in Washington, DC. The study director reports directly to the committee at its regular meetings and is further advised by an executive group formed by the committee's chair, past-chair, and chair-elect.

OPERATIONS

<u>Who may submit inquiries?</u>

Projects are undertaken by the Committee on Vision in response to specific inquiries from its supporting agencies and, occasionally, from other departments of government as called for in the congressional charter to the National Academy of Sciences. The expenses for such projects are covered by the annual funding from sponsoring agencies, or by specific contracts. Studies may also be undertaken in response to inquiries from sources other than federal agencies when the subjects are of general importance and appropriate to the committee. Inquiries and suggestions from outside sources about potential topics are welcome. The Committee on Vision may itself initiate studies on problems identified by its members.

How does the committee respond to inquiries?

The committee tries to respond as rapidly as possible to questions posed by supporting agencies. When the committee has already considered a problem or conducted studies on a question, answers can be provided immediately by the staff. More difficult questions requiring a synthesis of research from various fields are handled through specially appointed, task-oriented, small working groups and/or panels, whose deliberations often result in published reports. Members of these groups are selected from the general scientific community on the basis of expertise in the task area and ability to work as part of a problem solving team. Service in a working group or panel is recognized as a demanding and unique learning experience in applied visual science. The following are some examples of Committee on Vision (COVIS) publications [including (a) requesting agency, (b) sponsor, and (c) type of forum]:

1. Optical properties and visual effects of face masks, National Academy Press, 1977. [a.Army, b. Consortium funds for Committee on Vision (Core), c. Working group].

2. The multiple position letter sorting machine: As evaluation of visual, auditory, and human problems, National Academy Press, 1979. [a. U.S. Postal Service, b. Core and Committee on Hearing, Bioacoustics and Biomechanics, c. Working Group].

3. Visual research for flight simulation. W. Richards and K. Dismukes, Eds., National Academy Press, 1982. [a. Air Force, b. Core, c. Workshop].

4. Aging and visual function of military pilots. R. Sekuler, D. Kline and K. Dismukes, Eds., Aviat. Space Environ. Med. 53(8), 1982 [a. Navy, b. Core, c. Working group]. b. Core, c. Working group].

5. Aging and human visual function. R. Sekuler, D. Kline and K. Dismukes, Eds., New York: Alan R. Liss, Inc., 1982. [a. COVIS, b. Core, c. symposium].

6. Video display terminals and vision of workers: Summary and overview of a symposium. B. Brown, E. Rinalducci and K. Dismukes, Eds., Behaviour and Information Technology 1(2):121-140,1982.[a. National Institute for Occupational Safety and Health (NIOSH), b. NIOSH, c. symposium].

7. Nutrition, pharmacology, and vision. J. Dowling, L. Proenza and C. Atwell, Eds., The Retina 2(4):231-375, 1982. [a. COVIS, b. Core and Hoffmann-LaRoche, Inc., c. symposium].

8. Reading machines for blind people. D. Fender. J. Vis. Impair. Blind. 77(2):75-85, 1983. [a. COVIS, b. Core, c. Editorial].

9. Video displays, work, and vision. National Academy Press, 1983. [a. NIOSH, b. NIOSH, c. panel].

Through workshops, symposia, and newsletters, the committee provides a forum in which research scientists and those concerned with applied visual problems can interact.

CURRENT ACTIVITIES

The committee's recent studies have mainly involved four broad themes:

1) Measurement of visual function, including standards for clinical visual examinations, vision screening tests for occupations, and the development of new techniques for visual assessment.
2) Analysis of visual task and performance requirements for jobs such as piloting airplanes.
3) Effects of radiation and physical agents on the eye; and
4) Evaluation of optical and visual display devices.

Current active working groups are as follows:

Working Group 57: Emergent Techniques for Visual Assessment

The report of this working group has been submitted to the Committ e on Vision for their approval. This report will provide an objective analysis of new techniques and make recommendations regarding the feasibility of specific applications, especially those being considered by the Air Force and Navy who sponsored the project.

Working Group 58: Myopia Prevalence and Progression

This working group held its first meeting on August 15,16, 1984. Their goal is to submit a report within one year on the following issues:

1) What demographic and confounding variables must be evaluated in comparing older myopia prevalence data with current data?

2) Are there variables by which refractive error changes can be predicted for an individual?
3) What agenda for future research would substantially increase our knowledge of myopia prevalence and progression?

In addition, working groups are being assembled to study:

Aging Workers and Visual Impairments

This project is being sponsored by the Veterans Administration and the National Institute on Aging. The study will be divided into three parts:

1) Review and synthesize findings and discuss methodological problems in obtaining and validating research data. It would focus on at least the following issues: determinants, and progression of visual impairments in aging workers; assessment of loss of visual function in older workers; and maintenance of aging workers' performance through job modification; workstation design, technology adaptation, and employee training.
2) Examine the policy implications of the research findings and review the legal and ethical considerations involved in implementing various screening procedures.
3) Include a systematic set of recommendations for further research on aging workers and visual impairments.

Night Vision

This project is being sponsored by the USAF School of Aerospace Medicine. It will:

1) Define night vision. What are the parameters? (Dark adaptation, mesopic function, scotopic contrast sensitivity, dark focus, glare, etc.)
2) Update pertinent literature (recent innovations, new concepts).
3) Discuss true operational light levels (vision at night). (Scotopic versus mesopic versus low photopic and level of visual performance expected at these levels).
4) Review present methods of testing night vision. (Applicability for mass screenings).
5) Set specific guidelines for the design of a comprehensive night vision laboratory (incorporate in this design the inherent capability to build and evaluate a new system for screening night visual function).
6) Final products should be literature review, manuscript of proceedings, and other design blueprints.

Mobility Aids for People Handicapped by Low Vision and Blindness

This project is being sponsored by the National Institute of Handicapped Research. It will:

1) Summarize our understanding of the dimensions of the mobility problem in general.

2) Summarize the status of the various devices that have been designed and built to aid the visually impaired individual.

3) Assess the limitations of existing devices and potential new devices in terms of the basic dimensions of mobility in general.

<u>A Workers' Manual on Video Displays, Work and Vision</u>

The National Institute for Occupational Safety and Health and the National Academy Press have expressed interest in the preparation and publication of a popularized version of the NRC report on Video Displays, Work, and Vision.

These projects are fostering an interaction between research scientists and those concerned with applied visual problems. This interaction not only facilitates the application of basic science to the solution of specific problems, but it also helps inform scientists of new research needs and opportunities.

DISCUSSION

CAPT CONNON: This is addressed to the working group on myopia progression. At the Aerospace Medical Research Lab at Wright-Patterson we are going to go out to the Air Force Academy and review the records of the cadets. All 850 of the seniors will be reviewed for myopia progression trends throughout their years at the Academy and then we are going to do a random sampling of the other two years concerning the juniors and sophomores. The freshmen won't be looked at because they only have one entrance exam. They don't get another exam until the next year.

In that respect, I would like to get the input from the working committee on what exactly in the records we should look for. Should we consider just refractive error data? Should we look at case histories or family trends or anything like that?

We are also going to start a myopia control study at the Air Force Academy next fall, in which we will plan on using various types of new lenses, prescriptions and possibly even accommodative facility exercises, to see if there is any effect of those, either independently or combined, on myopia progression at the Academy.

DR. SHEBILSKE: The timing on this is superb, because we are now doing a literature review that should be completed by February [1985] and at that time we had planned to go into the recommendations. So, we will be addressing the issues that you are raising and, of course, we will be prepared to discuss them.

It seems to me that a flow of information both ways will be mutually beneficial. Is there anyone here on that working group that wants to add to that?

DR. BIEDERMAN: One charge of this working group has been to examine long-term trends, that is, in the last several decades. While this might be too much to ask of your immediate project, is there a data base at the Air Force Academy with a constant assessment procedure? This has been the problem in looking at these long/short-term trends; the assessment procedures change. However, if the procedures, the data base, really are constant and reliable then that could be of enormous utility to the Committee, to actually make an assessment as to whether there have been long term changes in myopia in the population.

CAPT CONNON I have been told by the people who keep the records that you can get refractive error changes. You can also get visual acuity readings for each year. However, the cycloplegic exams only occur twice and only twice for pilot candidates. They don't occur twice for just entering students. Those who have no desire to go on to pilot training, just have the cycloplegic at the beginning exam; whereas, the pilot trainees in the third year get another cycloplegic exam and, of course, they are highly motivated. So, if they see any change in their vision at all, they head into the clinic.

There was a standard operating procedure there to prescribe reading glasses to any cadet who requested them. One of the things we are going to look at on the records is who got the reading glasses and if there was a change related to that prescription.

DR. SHEBILSKE: On the issue that you will be addressing in December, I should say that already after our first meeting, I know that the working group will be making a distinction between the various kinds of myopia. That will be very important and they have already put their finger on some possible variables that might be useful in predicting progression over the time frame that you are interested in. So, we could begin discussing that immediately.

CAPT BAKER: I am concerned about the student naval aviator requirement that demands that he does not wear glasses. Take a 100 capable candidates for aviation and put them in a vertical list of capability based on their grade performance, their athletic performance, their motivation, whatever standard you want to use, assuming they are all physically qualified, and bring it down to the eyes. If we only have room for 50 in the incoming class, normally you would like to take the top 50 on that vertical list. I want the top 50 to go to flight training, but because a student might be 20/25, they say "no". Those who are already flying may have 20/50 vision, but a student must have 20/20 to be accepted into the Flight Program. Let's say that the top man on the list has 20/25. Immediately, I lose the top man on that list and I have to take No. 51 instead of No. 1. He doesn't become an aviator, perhaps he doesn't continue his military career subsequent to that. I think that is one of the most practical considerations this group might make.

I would like to have somebody provide me information that supports, really supports, the need for a student naval aviator to have 20/20 absolute, if, in fact, in the service we do fly with spectacles. We are accepting the fact that spectacles are going to be between an aviator's eye and the other devices that he is going to be using. What is the magic of someone that has already been trained as opposed to someone who starts out with glasses in the training command and functions that way?

I would much rather have a highly motivated, capable person with glasses than someone who doesn't have to wear glasses, who is halfway down on the average of a list. So, I am having trouble with that. In this two days, I have appreciated everything that everyone that is doing in their various areas of research, but this is a very basic problem. So, if there is anyone in the room who would like to set me straight as to why a student naval aviator can't start out with glasses and use glasses through his career--LCDR Heatley points out that when he didn't like going from 20/10 to 20/20 he went back to get some 20/10 spectacles. So we use spectacles. It is almost a religious procedure that these people be 20/20 as students, and I don't see that it is necessary.

DR. SHEBILSKI: One response that comes out in consideration of this problem (the increasing prevalence and performance implications of myopia) is the suggestion that there might indeed be more important considerations. I think that we heard that today. We heard the tremendous variability depending on experience; how the experience pilot with poor vision performs better than the inexperienced pilot. So, there certainly are many dimensions that have to be taken into consideration besides just acuity. This study that was motivated by the increased prevalence of myopia could have, in a long run, a more general solution to the problem of a change in standards.

Another way that the study might bear on this issue is that without any other factors that enable one to predict progression, the assumption is that a person that is better than another to begin with is less likely to progress, to become poorer. Whether or not that is true I don't know, but I think that is part of the logic behind it. What we are trying to do is take a very close look at whether or not there are variables that would allow us to predict progression. The result of that might also support your attempt to allow some pilots who may have 20/25 but whose variables indicate that they are very unlikely to progress beyond that.

CAPT BLACKWELL: If I may, I would like to address this a little bit, and maybe we might have something from the Safety Center or my successor in Code 14 on physical standards. But it has been discussed at length in the Aviation Aeromedical Advisory Council at NAMI, where in the room, I think we counted up 175 years of aeromedical experience. Dr. Briska generally carries the ball on this particular issue. There have been a lot of individual cases where there have been fathers of aviators, grandfathers or aviators, all kinds of political pressure and everything to make an exception for this or that guy. There are, I am sure, many cases where such an exceptional individual is really precluded from getting into aviation and he might well succeed; but we have found that even those who have trouble (they meet the 20/20 but maybe have to go through a second or third exam before they finish training) can no longer pass. It became our policy that if they were over halfway through, we would put glasses on them if they were performing well. The criteria were: if they were above average on their flight grades, if they were over halfway through, and if they got strong recommendation from their commanding officer, a waiver would be granted.

But Dr. Briska and the advisory council have taken a fairly hard stand on not accepting entrants because of the tremendous investment in these people who we have measured as marginal and who had difficulty meeting the 20/20 requirement. What is also seen as a problem is that when somebody first wears glasses, the glasses are much more of a hinderance, bother and distraction than someone who has been wearing them for years.

We feel that if a guy has 20/25 in one eye and 20/20 in the other, and has no idea that he needs glasses, has never worn glasses, is halfway through training, and he is just coming up on night carrier or FCLP landing practice and he is told that he is going to have to wear glasses and he starts having a bunch of reflective lights dancing around off the frames or the two surface of the lens, it may be too much. That is the basis primarily for our position, because we have not as yet developed these other tests of visual function besides visual acuity.

At this point in time, visual acuity is our single best index of all of the visual function parameters. If we can get something that says that, we can test these other factors and show that visual function is that good even with 20/25, then maybe we have got a case. But right now these tests are not in place.

MAJ MCLEAN: I don't think this will answer your question, but the Army did a study back in the sixties. We had difficulty getting people who wanted to fly helicopters back in the middle sixties, especially when people were shooting, and previously they had always had more people for the number of positions than could be selected. When we couldn't get enough people, the first thing they waived was the visual acuity requirement. They went to what is called a Class 1-A standard, which is like the navigator for the Air Force, and there was a lot of concern about whether these people could fly the aircraft or would there be any difference. It was looked at by both academic performance and flight evaluations. At the end of the program, they found no difference between the two groups, with the exception that possibly the guys wearing glasses were better academically, equal or maybe a hair better also flight-wise.

As soon as the little exercise over in Southeast Asia ground down, we had again more people than they could fill, so we ended up going back to Class 1 standards again. It is kind of like a promotion board. You know, you have got so many slots that you can fill and they look for excuses to knock them out.

Also, there are problems with glasses. I don't care what pilots tell you, that there are no problems. There are problems with glasses. They fog. They don't fit with the night vision goggles. They break, especially if you want to eject and you can't always assure that your visor is down or it is locked. They vibrate when you are pulling g loads or fall down on your face. On a helicopter they can really vibrate. Depending on the power, you say, well, how much? What level are you going to allow a person to have? Well, 20/25. Why not 20/30? Why not 20/100? And particularly with the Navy, you know you are getting less and less aircraft, which is going to mean fewer pilots. The Israelis select one out of 300 applicants so--

DR. EMORY: I am Code 14, the aerospace physical qualifications, and formerly I ran the physical exam room at NAMI for two and a half years, so I am the one that NPQ'd all these candidates with 20/25 vision.

There are several factors involved. We don't know at what level an aeronautical engineering student, with his private or commercial license and an instrument ticket, can enter the naval program and complete it with successful CQ with above average scores. We don't have functional testing to find that out. Now, there was a myopic study program done in the Navy in the sixties. In reviewing physicals at the present time, I note that many of these people that were admitted with minus a quarter, minus a half, minus .75 lenses were, in fact, now Service Group 3 and are not even in the Navy. We don't have the performance data on how they flew available at my office, but that is probably available somewhere within the Navy.

Another program that has been going on for the past three or four years is the transition program. The designated Navy flight officers who have successfully completed a fleet tour, and who are classified as highly motivated and excellent officers, are brought back to Pensacola to transition as naval aviators. There have been some 300 of these people brought back and the completion rate through the Navy training as pilots and carrier qualifications has been alluded to. I don't have the actual figures right now, but it is alluded that less than 50% of these people will transition. The only difference in requirement between then and our normal 20/20 of student naval aviator is the fact that they meet Service Group 1 standards, 20/50 not to exceed minus 1.25 diopters of myopia.

The failure rate on these people may be related to vision or it may be related to the fact that they are a couple of years older and have more common sense.

DR. SHEBILSKI: By the way, the Committee on Vision, I understand, has a report summarizing some of those data, so if people are interested in looking back at some of those numbers, they should write to the Committee and get a summary.

DR. EMORY: A final point I would like to cover while I am here is the validation of the 20/20 test of the applicants that come to NAMI as student naval aviators, the current failure rate having been screened elsewhere (Air Force, Naval Air Stations, local community optometrists, and ophthalmologists); the failure rate today is 25% for student Naval aviators. They are screened as being 20/20 when they come to us, but when we start presenting random non-memorizable tests and the hundred letter chart and/or using the BVAT presenting random letters, these people fail to pass the 20/20. One problem with that statement is that our definition of 20/20 is apparently different than most everybody else's. We are requiring them to read ten letters on the 20/20 line, and most of you will admit that minus 2 or minus 3 is within the ball park of being called 20/20.

DR. SHEBILSKI: We are planning stages for night vision and I understand, given the dictum "lose sight, lose the fight," there is as much emphasis on identification as on recognition and all the things we have been talking about here; but, I wonder if there are important situations, especially those that occur at night, where it is important for military personnel to know where a target is, what size it is, how it is oriented; that is, not only knowing what it is, but knowing where it is.

The reason I am putting that question to you is, in designing a study, should we be including people in the basic research community or applied research community studying those issues as well? I can just tell you, for instance, that people collecting data on perception of egocentric orientation where a target appears to be located with the self, how a line or a runway appears to be slanted with respect to the self, what size an object is and so on, find tremendous individual variability in that. Should we be assessing that? Is it important? Could there be performance implications? I would just appreciate some input on whether that should be a topic under night vision study or not.

CAPT BLACKWELL: If I may impose on CAPT Houk, maybe he will address some of the plans for the performance testing and predictors for aviation performance. The list and ranking of 1 to 50 and 1 to 100 is based on an assumption of which I am not clear, and that is that we can rank these people and we predict their success in aviation. To my knowledge, that has never been done. We have been spending a lot of money trying to figure out good predictors for success in the aviation flight training program, and maybe CAPT Houk will mention that in his closing remarks.

CAPT BAKER: I think the only comment on that is that we don't have any data, and we are all making assumptions as to whether or not this makes a lot of difference in their performance. We don't have a test group that has gone through with other than 20/20.

CAPT HOUK: I will just try to give a short capsule here, mainly for general awareness.

In 1977, the Deputy Chief of Naval Operations for Air Warfare identified a requirement, a very clearcut requirement, that dealt with age. What he wanted to know was, "Why not an age-free standard? What is sacrosanct about age?"

The second line of his requirement statement was more subtle, and that was, "What are the alternatives to age if age isn't an adequate criterion?" It took folks a couple of years to muddle around to find out that age wasn't adequate. It is an administrative criteria that can be adjusted upward or downward by the Chief of Naval Operations or some other equivalent in one of the other services, such as a Chief of Staff, as he deems appropriate. You can see how any standard can be adjusted upward or downward according to your through-put requirements of pilot training requirement or whatever you want to call it. These are somewhat arbitrary. Now, in the parallel development many of you are aware, particularly those who have been involved in selectio for any duration, that this, in fact, is in law. n law you must have a validated data base against which you set a standard or demonstrate job relatedness. The latter one is tough. You have to have proper criteria, and we have just begun to figure out the mechanism for this in the operational setting.

It is on this philosophical base that we entered into a program, and I know the Air Force has a parallel program very similar to it, called a performance-based biomedical standards development. First of all, we have to identify the performance criterion you are talking about, which we are in the process of doing, and with varying degrees of success, and become familiar simultaneously with that criterion environment represented by our fighter pilot. This is one of the reasons we are collecting most of our vision data on the range right now, and isolating one particular aviation task which is air-to-air acquisition. By taking everything we know, and factors that other folks have come up with in testing modalities and procedures, we may be able to see what tests relate to performance and then refer back to our standards base, represented by the institute, and try to link the two together.

Everybody in this room is involved to some degree or another in just that program. It is a very ambitious program. It is a tough one, but it is getting us in the real world where we belong, finally after all these years.

I agree with you [as far as the 20/20 requirement], but there is not an immediate solution and you can't drop the standards or you have chaos. You have to have the alternative in hand as you go forward. We all agree that something was set arbitrarily in 1953, locked in the bible that is called Manual of the Medical Department (for those of you who don't know), Chapter 15. It becomes the bible and that is all we have got, and everybody forgets what happened in 1953 to set those standards because the references aren't listed, and you would have to go back into the literature base. Frequently, it was somebody's judgment, based on his experience, and that is how the number gets emblazoned in stone, as LTCOL Genco said earlier. That is what we have to deal with.

This is what is going on and this is how we are all trying to deal with it, and one of the reasons many of the speakers here were invited to speak. This is the kind of work they are doing and how they come to grips with it. And, yes, we need that feedback. That basically is the requirements-statement for the whole program.

DR. MONACO: I have a question of Dr. Chris Johnson. Historically, the standard clinical measurement of perimetry or visual fields required a central fixation target that is a static target. In our real-world environment that we are dealing with in the military, we know that central fixation is not limited to a static target. The central fixation is confounded by moving things, dials, gauges and buzzers. There is a wealth of literature that maybe Dr. Williams can expound on that deals with what they have coined the functional visual field.

One thing we have been toying with in developing an automated vision testing battery is to make it usable to the flight surgeons and vision specialists in the fleet. We have tried to use existing clinical tools and modify them in such a way that they can be used for a dual purpose. For example, taking something as simple as an arc perimenter, and changing the central fixation target that is static to one that is dynamic, one that requires maybe some cognition or some visual interpretation. While that is happening, can we then measure the influence on the peripheral visual fields? Are there current devices available?

DR. JOHNSON: I can just give a couple of comments. The ophthalmologic community or, at least, that section of the ophthalmologic community in the ophthalmic sciences community that has been interested in visual field testing, has not addressed any of the functional problems per se. It has been people that have been interested in functional visual fields and things of that nature that have really addressed this.

Several years ago, the International Perimetric Society, which is a group of individuals that are interested primarily in clinical visual field testing, but also just visual field testing and peripheral vision in general, started working group, if you will, on the occupational visual field and looking at the ergonomic factors, not necessarily with the standard clinical test procedures, but looking at things like the functional visual field and looking at different modes of presentation.

I would say right now that the existing automated devices and the existing manual devices can be modified, but I think the major drawback there, if you are going to look at a commercially available product, is that it is going to require a great deal of effort on your own part to convince the manufacturer that it is worth their while to make the modifications. We have had some success with that because we had to make a fair number of modifications for the screening. That is not a typical clinical trial because you don't test in two minutes. On the other hand, we have had times when it has been very difficult to do that and the details that are offered by the manufacturer are not sufficient to do your own modifications with any degree of confidence. So, I think it is in the early stages. Certainly, those are important issues that the ophthalmic community has not addressed in a direct fashion, but there is an interest. There are a number of people that are now becoming interested in that, and I have noticed that since we have done this study, there have been four or five studies in Europe that have been done on the relation of peripheral vision and driving, just looking at a simple function like sensitivity to light, just a standard type of visual field.

There are also efforts to look at orientation and mobility characteristics and adaptations of standard clinical tests to looking at functional visual field characteristics and how that interacts with performance-related criteria. So, it is in the formative stages but there is nothing in terms of a large literature or available devices for doing that, easily, right now.

DR. WILLIAMS: In response to your question, I guess I am not really aware of that particular paradigm having been used. There have been a number of studies that have used a central tracking task, obviously, dealing with very slowly moving targets, and intermittently some sort of a peripheral stimulus would appear, maybe a light, and a subject would have to respond to light. But, what people were really looking at was how did that peripheral target onset perturb performance on the ongoing central tracking test. It is, more or less, the opposite of the functional field approach. I guess the answer to your question is that I am not sure anyone has looked at a moving foveal target. I guess you could move it over a very wide range. It wouldn't be a foveal target, but you could move it to some limited extent and look at how it perturbed, or if it perturbed, some sort of peripheral, secondary sort of task. I have also found that when you use a response time, a reaction time, sort of dependent measure, as people are increasingly doing, there is an awful lot of speed stress involved, and I really think there is a possibility for the functional field being very much affected by speed stress. This was looked at many years ago, not very intensively, and it seems to have lost favor in recent years. So, you might want to consider the kind of dependent measure you are using. As I reported in my paper, I get some differences with just accuracy measures as opposed to when you are really under some speed stress.

APPENDIX A

SPEAKERS
(In alphabetical order)

SPEAKERS' BIOGRAPHICAL SKETCHES

Anthony J. Adams, Ph.D.
School of Optometry
University of California, Berkeley

Dr. Adams, after clinical optometric training in Australia, earned a Ph.D. in Physiological Optics from Indiana University and then taught there for two years. He has been a Professor of Optometry and Physiological Optics at the University of California, Berkeley, School of Optometry since 1968, and Director of the Ph.D. graduate training program since 1975. He has published over 50 papers dealing with visual performance and drug effects, neurophysiology and psychophysics of visual disorders. He is currently an elected member of the NAS-NRC Vision Committee, Vice President of the National Board of Examiners in Optometry and is an NIH-NEI Training Grant Director in Physiological Optics.

Isaac Behar, Ph.D.
Army Aeromedical Research Laboratory
Fort Rucker, Alabama

Presently, Group Leader, Visual Science Research Group of the Army Aeromedical Research Laboratory, Fort Rucker, Alabama, where he has conducted studies on contrast sensitivity, dynamic visual acuity, and the effects of fatigue and vibration on visual performance. From 1960 to 1973, he was affiliated with the Army Medical Research Lab, Fort Knox, Kentucky, where the emphasis of his work was on simian visual discrimination processes. His undergraduate training was received at Brooklyn College, the M.S. at Tufts where he was introduced to applied vision research, and the Ph.D. at Emory where he was University Fellow.

Ray Briggs, Ph.D.
State of California
Commission on Peace Officer Standards and Training

Dr. Briggs, is currently a Research Specialist for the State of California, Commission on Peace Officer Standards and Training. Prior to this, he was a National Academy of Sciences Fellow (1980-1982), where he explored various issues related to visual standards and aging. From 1978-80, he served as a research associate at Cal Tech in the Department of Biology, (Bioinformation Systems) where he worked on eye movement contingent displays. He has also been a faculty member at the Claremont Colleges, Oakland University, and Cornell University, where he did research on coding strategies and visual distinctive features.

Walter William Chase, O.D.
Southern California College of Optometry

Dr. Chase received his optometry degree from Indiana University in 1960, and the M.S. degree in Physiological Optics from I.U. in 1963. He left the graduate program in 1966 to accept a teaching position at the then Los Angeles College of Optometry, now the Southern California College of Optometry in Fullerton, CA. While there, he has served as Director of Student Research, Chairman of the Department of Basic and Visual Science, Director of the Research Computing Center, and is currently President of the Faculty Council while fulfilling his obligations as Professor of Visual Science. His consulting and research activities are primarily in the areas of visual optics and ocular motility.

Thomas R. Connon, CAPT, USAF, BSC
Air Force Aerospace Medical Research Laboratory
Wright-Patterson AFB, Ohio

Captain Connon, a research optometrist, is head of the Physiological Optics Facility at the Aerospace Medical Research Laboratory. Recent research efforts undertaken by the facility include studies on pilot night vision capabilities, target detection parameters, and diplopia threshold through the wide field of view HUD. Currently, he is studying the visual-vestibular aspects of space adaptation syndrome as well as changes in visual function due to a microgravity environment.

Jeffrey L. Craig
Air Force Aerospace Medical Research Laboratory
Wright-Patterson AFB, Ohio

Mr. Craig is an Industrial and Systems Engineer within the Human Engineering Division of the Air Force Aerospace Medical Research Laboratory. Working primarily as an "applications" engineer, Mr. Craig has been instrumental in the design, installation, flight testing, and evaluation of several operational test items. Included among these items are Night Vision Goggle compatible lighting systems, Night Vision Goggle Heads-Up Displays, and external strip lighting for aerial formation and refueling.

Louis V. Genco, LT COL, USAF
Air Force Aerospace Medical Research Laboratory
Wright-Patterson AFB, Ohio

Lieutenant Colonel Louis V. Genco is the Deputy Director of the Air Force Aerospace Medical Laboratory's Human Engineering Division, and the Chief of the Crew Systems Effectiveness Branch within that division. As a research optometrist, he has been involved with several critical efforts related to USAF operations, including the development of performance-related specifications for aircraft transparencies (windscreens, canopies and

HUDs [Heads Up Displays]), improved visual aids for aircrew and special forces, and the development of devices used to quantify changes in visual functions aboard space shuttles. Recently, members of his branch have started to design several new, portable vision testing systems for the Navy, NASA and the Army, each testing human performance on the subset of visual parameters, chosen specifically for the test applications.

Arthur P. Ginsburg, MAJ, USAF
Air Force Aerospace Medical Research Laboratory
Wright-Patterson AFB, Ohio

Major Ginsburg is the director of the Aviation Vision Lab, Air Force Aerospace Medical Research Laboratory. His education includes B.S.E.E. (Widener College, 1969), M.S.E.E. (AFIT, 1971), and Ph.D. in Biophysics (University of Cambridge, 1980). Major Ginsburg's main interest is basic and applied vision research using linear systems analysis to determine filter characteristics of overall and individual mechanisms of human vision and application of that knowledge has relevance to vision standards, operator performance, display quality, and visual target acquisition under static and dynamic conditions, such as vibration, high g-stress, hypoxia, and in space. He is a member of Tau Beta Pi, Sigma Pi Sigma, Sigma Xi, The Optical Society of America, and The American Association for the Advancement of Science.

Charles J. Heatley III, LCDR, USN
VF-124
Miramar, California

Lieutenant Commander Heatley is a Navy Fighter Pilot, photographer, and author of various articles on Visual Signature Reduction/Aircraft Camouflage Paint Schemes. He received a B.J. in 1972, at the University of Missouri (Photojournalism). He has accumulated more than 4,000 flight hours and 600 carrier landings with VF-74, Topgun, the 64th and 65th Aggressor Squadrons, the 4477th Test and Evaluation Squadron, VF-1 and VF-124. He is an instructor at both the Navy and Air Force Fighter Weapons Schools.

Jerome B. Hodge, CDR, USN
VF-43
Oceana, Virginia

Commander Hodge reported to Flight Training in June 1968 and was designated a Naval Aviator in September 1969. In November 1970 he began Fleet Replacement Pilot Training in the F-4B in Fighter Squadron ONE TWO ONE, NAS Miramar, San Diego, and was subsequently assigned to Fighter Squadron ONE FIVE ONE, where he made two deployments to Southeast Asia aboard the USS MIDWAY. Commander Hodge returned to Fighter Squadron ONE TWO ONE in June

1974 as the FRAMP Officer. Remaining at Miramar, he reported to Fighter Squadron ONE TWO FOUR in 1977 for Fleet Replacement Pilot Training in the F-14, and subsequently reported to Fighter Squadron TWENTY-FOUR. He made two deployments to Southeast Asia with the RENEGADES aboard the USS CONSTELLATION. During his aviation career, he has accumulated over 3000 flight hours and 500 carrier landings. His personal awards include an Individual Air Medal with ten Strike/Flight Awards, four Navy Commendation Medals with Combat "V", the Presidential Unit Citation and the Vietnam Cross of Gallantry with Gold Star.

Chris A. Johnson, Ph.D.
Department of Ophthalmology
University of California, Davis

Dr. Johnson received his Ph.D. in 1974 from the Department of Psychology at Pennsylvania State University, under the direction of Dr. Herschel W. Leibowitz. From 1975-1976, he was an NIH postdoctoral research fellow in the laboratory of Dr. Jay M. Enoch in the Department of Ophthalmology, at the University of Florida School of Medicine. In 1977, Dr. Johnson moved to the University of California at Davis, where he is currently an Associate Professor in the Department of Ophthalmology, School of Medicine. His research interests include automated visual field testing, accommodation responses of the human eye and visual factors related to transportation safety, aviation and industrial environments.

Herschel W. Leibowitz, Ph.D.
Pennsylvania State University

Dr. Leibowitz did graduate work in experimental psychology at Columbia University and was on the staffs of the University of Wisconsin and IBM before moving to Pennsylvania State University. Post-doctoral work includes the Max Planck Institute for the Physiology of Behavior, The Institute for Perception, the Universities of Freiburg and Florida, and the Center for Advanced Study in the Behavioral Sciences.

William E. McLean, MAJ, USA
U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama

Major McLean has been assigned to the U.S. Army Aeromedical Research Laboratory at Fort Rucker, Alabama, from 1969-1970 and 1980-to the present. His research efforts have primarily been in night vision goggles, helmet display unit, peripheral vision, optical evaluations, and vision in aviation. Academic background includes a M.S. in Physiological Optics from the University of Houston and an O.D. from the Illinois College of Optometry.

Robert E. Miller II, MAJ, USAF
Aerospace Vision Laboratory
USAF School of Aerospace Medicine (AFSC)

Major Miller received his O.D. and M.S. (Physiological Optics) from Indiana University in 1970 and 1982, respectively. He has been a clinical optometrist in several USAF Hospitals including RAF Lakenheath, England. Presently, he is Chief of the Aerospace Vision Laboratory, Ophthalmology Branch, Clinical Sciences Division, USAF School of Aerospace Medicine, Brooks AFB, TX. Major Miller is a Fellow of the American Academy of Optometry, and his interests are night vision and aeromedical applications of soft contact lenses.

Kirk Moffitt
New Mexico State University
Las Cruces, New Mexico

Mr. Moffitt is currently a doctoral candidate in the Department of Psychology at New Mexico State University. He received his B.A. from Wichita State University in 1973 and his M.A. from New Mexico State University in 1978. His research interests include eye movements, visual accommodation, and the testing of vision.

Efrain A. Molina
Naval Aerospace Medical Research Laboratory
Pensacola, Florida

Currently, Electronics Engineer at NAMRL in the Medical Systems Division, Mr. Molina holds a B.S.E.E. from Christian Brothers College in Memphis, Tennessee, a M.S.E.E. from Tulane University School of Engineering in New Orleans, and a M.A. in Applied Mathematics from the University of West Florida in Pensacola.

William A. Monaco, CDR, MSC, USN
Naval Aerospace Medical Research Laboratory
Pensacola, Florida

Commander Monaco is a 1968 graduate of the Los Angeles College of Optometry, with a M.Ed. from the University of Southern California and a Ph.D. in Physiological Optics from the University of Houston College of Optometry. He has been stationed at NAMRL since 1981 and is presently Chief of the Vision Sciences Division.

William A. Morey, Ph.D.
Naval Aerospace Medical Research Laboratory
Pensacola, Florida

Dr. Morey received a B.S. degree from the University of West Florida at Pensacola, his Masters and Ph.D. in Neuropsychology and Neurophysiology at the University of Utah. He is currently Research Physiologist at NAMRL in the Vision Sciences Division.

D. Alfred Owens, Ph.D.
Whitely Psychological Laboratories
Franklin & Marshall College
Lancaster, Pennsylvania

Dr. Owens received his Ph.D. in 1976 at the Pennsylvania State University. From 1976-78, he was a Research Fellow at Massachusetts Institute of Technology. From 1978 to the present, he has been a member of the Psychology Department at Franklin and Marshall College in Lancaster, PA.

Ralph E. Parkansky, LCDR, MSC, USN
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Lieutenant Commander Parkansky received a B.A. degree from Western Illinois University, a D.O. degree from Illinois College of Optometry, and a M.S. degree in Physiological Optics from the University of Houston. Currently, Lieutenant Commander Parkansky is Chief of the Optometry Division, Naval Aerospace Medical Institute, Naval Air Station, Pensacola, Florida.

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Dr. Regan obtained his B.S. and ARCS in physics in 1957, M.S. and DIC in optical physics in 1958, and Ph.D. in physics in 1964, all from Imperial College, London University, England. He was awarded a higher doctorate (D.S.) in 1974. After lecturing in physics at London University, he spent 12 years in the Research Department of Communication and Neuroscience, University of Keele, England. In 1975, he moved to Canada as Killam Research Professor at Dalhousie University where he is currently Professor of Ophthalmology and Medicine.

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Dr. Shebilske received a Ph.D. from the University of Wisconsin in 1974 and joined the faculty at the Department of Psychology, University of Virginia in the same year. He has published numerous scientific reports on comprehension during reading and visuomotor coordination during natural event perception. He has also co-authored a textbook: Psychology: Principles and Applications. He is currently on leave of absence from his position at Virginia and is serving as study director of the Committee on Vision at the National Academy of Sciences.

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Mr. Sheehy is a doctoral candidate in the experimental psychology program at the Pennsylvania State University (expected graduation 12/84). He received a M.S. in engineering psychology from Rensselaer Polytechnic Institute in 1980. Current research interests include dynamic visual performance, visual and attentional demands of driving and of the highway environment, and the evaluation of psychological responses to stressors in the workplace and in situations demanding skilled performance.

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Dr. Williams has been an assistant professor in the Human Factors doctoral program of the Department of Psychology at the University of South Dakota for two years. His general research interests are in visual perception and attention, particularly as they relate to Human Factors. The majority of his publications pertain to divided attention and the functional field of view. Dr. Williams is a member of many professional organizations including Sigma Xi, Human Factors Society, Midwestern and Southeastern Psychological Associations.

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The Tri-Service Aeromedical Research Panel (TARP) Fall Technical Meeting was held on 13-14 November 1984 at the Sherman Inn, 224 East Garden Street, Pensacola, Florida.

Invitees were the TARP membership, the TARP member laboratories representatives from the three services' R&D communities, as well as other relevant military and civilian communities. The purpose of the meeting was to provide a forum for information exchange between vision scientists and clinicians from all three services as well as the civilian scientific community. The emphasis

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) of the presentations was on vision research relevant to problems affecting military aircrew performance. This meeting served to ensure close inter-service cooperation in vision research, and to assist in identifying future research requirements. Topics included:

- Contrast sensitivity
- Dark focus/night vision
- Ocular motility
- Accommodative flexibility
- Depth perception
- Clinical visual parameters
- Visual screening
- Human factors in aviation
- Dynamic visual acuity
- Visual performance thresholds

The two days were devoted to invited talks and discussions within these topical areas, and concluded with a report from the National Research Council Committee on Vision.