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NAVAL AVIATION VISION STANDARDS RESEARCH AT THE NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY: THE LONG VIEW

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Commanding Officer

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ABSTRACT

The Naval Aerospace Medical Research Laboratory (NAMRL) has been pursuing a research program to develop easily administered tests of vision skills that are valid, practical tools for the selection of personnel likely to be successful in the naval aviation arena. From 1980 to 1985, NAMRL maintained a data collection effort measuring the vision of U.S. Navy fighter pilots assigned to the air-to-air combat training range (NAS Oceana, VA). Both operational performance and vision test data were collected from the pilots. This report presents a) the underlying theoretical orientation that guided that research effort, b) a summary of the research results to date, and c) the ideas guiding the design of the research strategy projected for the future. For convenience, abstracts of the principle publications describing this work are assembled in the appendix.

ACKNOWLEDGMENTS

This work would not have been accomplished without the significant participation and contributions of each of the following individuals.

CAPT James Goodson was responsible for the initial design, planning and organization of the project from 1972 to 1982.

Dr. James Grissett, an excellent former Department Head and Chief Scientist, provided guidance as well as administrative and moral support enabling this project to reach its current stage.

Dr. Paul V. Hamilton provided invaluable statistical analysis skills and support at the initial data analysis stages of the project.

Mr. Efrain Molina provided essential engineering support from the initial design of the test apparatus, through the fielding of the apparatus at Oceana to the various stages of the data analysis.

CDR William Monaco guided the project from 1982 to 1985, coordinating the major Oceana data collection effort and proceeding with the initial data analysis efforts.

Dr. Ailene Morris contributed immeasurably to the design and instrumentation of the NAMRL Automated Vision Test Battery. The vast majority of the vision test data collected at Oceana was collected by Dr. Morris and Mr. Ed Ricks. Until her retirement, Dr. Morris provided an essential store of corporate knowledge that has enabled the analysis of the data to transition to new personnel who were not involved with the design of the project or the data collection effort.

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CDR D. L. Still, a truly supportive colleague, provided insight and statistical support enabling much of the analysis, some of which does not include his name as an author.

INTRODUCTION

The Chief of Naval Operations (CNO) requested the Bureau of Medicine (1) to evaluate alternatives to chronological age as a determinant for flying classification, to develop alternatives or improved systems of monitoring examinations, and to determine if validated predictive systems can be formulated. This was interpreted as a request to provide standards of personnel selection and retention that have been validated by a demonstrated relationship to successful aviation performance. Current vision standards for the selection and retention of naval aviation personnel primarily address corrected and uncorrected visual acuity and the absence of any indications of ocular pathology or anomalous color and binocular vision. Although these criteria are based on 'common sense' and expert clinical opinion, they do not definitively demonstrate that the medical standards are valid predictors of success in the performance of tasks essential to naval aviation or whether there are other standards of visual function that should be incorporated.

THE INITIAL RESEARCH

VISION TESTING AT NAS OCEANA, VA

The Naval Aerospace Medical Research Laboratory initiated a research program designed to address the CNO's request (2). The research program emphasized visual functions that the investigators thought would correlate with air-to-air target detection in daytime Air Combat Maneuvers (ACM) and with night carrier landing performance.

Several considerations contributed to the selection of air-to-air target detection as a criterion of operational performance. First of all, it is obviously a critical military aviation task that depends heavily on vision. The fighter community places a great deal of emphasis on first detection of the adversary in ACM because first detection can provide a tactical advantage in the formation of strategy and maneuverability. Air-to-air target detection is fundamentally the detection of a spot of light in an essentially empty field. This is a task heavily dependent on central visual function, involving the detection limits of the fovea. In fact, the performance of this task is one of the reasons that, in the past, the naval medical and line communities have set such stringent standards for uncorrected central visual acuity.

Another reason for the emphasis on air-to-air target detection was that with the telemetry technology available at the time, it was possible to obtain precise measurements of target detection distance as well as numerous environmental variables that provide a complete description of relevant stimulus parameters. With this information, air-to-air target detection can provide a relatively accurate, rigorous, and unambiguous measurement of pilot performance in the field.

Night Carrier Landing performance was selected because a) the pilot uses vision to land the aircraft on the carrier (i.e., the task is a visually guided one); b) each carrier landing is rated by an expert, the Landing Signal Officer (LSO), so that the performance of each pilot is rigorously scored and is available from the pilot's flight record; c) and night carrier landing is probably the single most difficult military aviation task to be performed on a routine basis.

The research strategy elected by NAMRL personnel was to measure, in a laboratory setting, the performance of pilots on a battery of vision tests and correlate the laboratory measurements with a) their air-to-air target detection distances recorded during ACM training, and b) their recorded night carrier landing scores.

The battery of vision tests emphasized central, that is, foveally central (as distinct from neurally central) visual capabilities. This emphasis was consistent with the fact that air-to-air target detection is a task heavily dependent on central vision. The NAMRL vision test battery included measures of static high-contrast acuity, static low-contrast acuity, near high-contrast acuity, dynamic visual acuity, reaction time, spot detection, a psychophysical measure of accommodative flexibility, contrast sensitivity, and dark focus (2).

The tests were instrumented in a field testing laboratory facility that was made operational at the Tactical Air Combat Maneuver Training Range at NAS Oceana, Virginia, and were used to measure the vision of about 180 U.S. Navy jet pilots during the time they were stationed there to engage in ACM training. The administration of this vision test battery required about 3 h for each subject. The subjects were tested individually.

The data collection was completed in 1985. Since then, we have been analyzing the data base, which has proved to be a rich source of information, providing insights concerning the vision of Navy jet pilots. These data and their analyses have been documented and reported in several publications (4-15), which are summarized in the appendix.

LIMITATIONS OF THE VISION TESTING AT NAS OCEANA, VA

As the analysis of these data progressed, gaps and limitations of the data base have become increasingly clear. This should not be taken as an indictment of the data base, nor an indication of errors or oversights in the design of the research project, but rather the consequence of a productive program of research whose results caused a clarification and sharpening of questions.

The major limitations of the fighter pilot data base are:

a. Pilot visual capabilities are only one determinant of air-to-air target detection in the ACM arena. It is easy to generate an almost limitless list of factors that could be more important determinants of air-to-air target detection than the visual capabilities of pilots. Such a list should include not only the environmental factors of weather, atmospheric visibility, time of day, season of the year, sun position, and sun angle, but also the effects of hardware, helmets and their visors, windscreens, and the adequacy of spectacle correction if used, as well as the specifics of the aircraft, cockpit, and electro-optical aids. Furthermore, pilot motivation, experience, and other psychological and physiological factors are also important. Thus, vision is only one of many factors that influences pilot performance.

b. The range of individual differences in pilot flying performance is narrow because all the pilots are experts. In other words, at this stage of their career, those pilots whose performance was significantly poor had already been excluded from the subject pool. Thus, the variability attributable to differing aviation skills of the pilots is a small percentage of the total variability.

c. Operational performance is difficult to measure in a rigorous, valid, reliable fashion.

d. Nearly all of the vision tests that were selected for use with the jet pilots were selected because the tests assess skills closely related to air-to-air target detection. In other words, the tests were all measures of some aspect of central or foveal vision. This is a double-edged sword because, on one hand, the emphasis on foveal vision was consistent with research designed to correlate central vision with air-to-air target detection. On the other hand, there was a great deal of redundancy among the vision measures; they all measured closely related vision skills, and several were highly correlated among themselves.

e. All of the pilots had to have excellent foveal vision -- one of the requirements for entry into the flight program to become a Navy jet pilot. Because of this, the range of vision test performance was narrow, and the variability attributable to the different vision skills of the pilots was small.

To appreciate the impact of these five factors, it is important to remember that the experimental approach was correlational; that is, as illustrated in Fig. 1, the correlation between the vision test and operational performance was calculated and plotted to reveal an underlying functional relationship between the variables. These five factors combine to pose a complex of special problems for the statistics of correlation.

The Range Restriction Problem. The restriction of range is one such problem that is unfortunately resistant to a convincing solution. The range restriction problem is that, with all things being equal, the size of the correlation is dependent on the range of scores; the greater range of scores, the greater the correlation (16). To use a simple illustration, it is easier to predict individual differences in academic performance for a group of students whose IQs range from 50 to 150 than for a group with IQs ranging from 90 to 110. In the limiting case, when the range has been restricted to zero, there would be a zero correlation.

An extreme case of the restriction of range is illustrated in Fig. 2. Over the full range of scores, the correlation will be much larger than over the smaller range outlined in the smaller square.

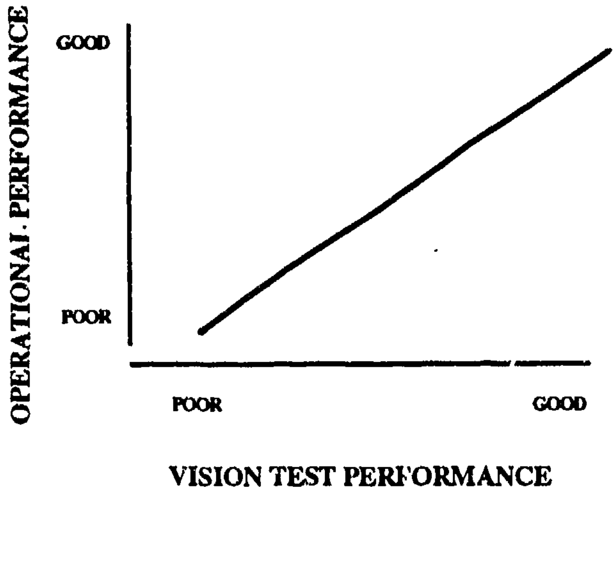

Figure 1. Schematic of the assumed underlying relationship between some vision test, on the x-axis, and some measure of operational performance on the y-axis. Poor vision test performance would be associated with poor aviation performance, and good vision test performance would be associated with good aviation performance.

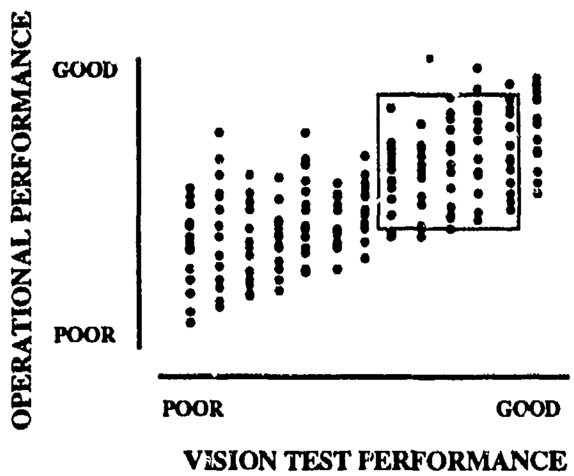

Figure 2. An example of the effects of a restricted range of measurements. A strong linear relationship is evident between variables 1 and 2 under conditions permitting measurements over a extended range. When the measurements are confined to a smaller range, as indicated by the small, bold box, the scatter in the data is increased, obscuring the underlying linear relationship.

The Oceana, Virginia, jet pilot data base has the necessary and sufficient conditions for the restriction of range as illustrated in Fig. 3. Because all of the pilots have excellent vision, the data are constrained to lie in the upper range of the abscissa. Similarly, because all the pilots exhibit good aviation performance, the data are constrained to lie in the upper range of the ordinate. These two constraints combine to restrict the data to the upper right quadrant of the graph.

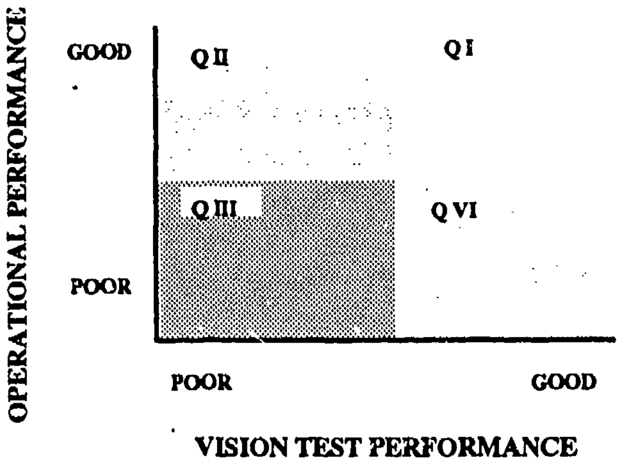

Figure 3. A depiction of why the range of measurements obtained from the Navy fighter pilots is restricted on the x-axis to the region of good vision performance and on the y-axis to the region of good aviation performance. Since pilots' superior vision excludes data from quadrants II and III and pilots' superior operational performance excludes data from quadrants III and IV, the data are constrained to quadrant I.

Figure 4 illustrates the influence of the restriction of range on actual data. The ordinate reflects ratings of each subject's night carrier landing performance (NCLS). The rating scale runs from a high of 4 to a low of 0. Each landing of each subject is rated on this scale by the landing signal officer of an aircraft carrier. The abscissa reflects each subject's performance on a vision laboratory test. It is the minimum presentation duration of two targets, one presented at 18 inches and the other at 18 feet in front of the subject. Both of these targets were 1.0 min of visual angle, and the subject had to resolve both of them, first the near one then the far one. The abscissa reflects the threshold target presentation duration, in seconds, required for the subject to resolve both targets. Each point represents a different subject.

Night carrier landing scores range from 2.9 to about 3.8 of the possible range of 4.0; that is, all the scores use only 20% of the possible range, and are all within the upper 25% of possible ratings.

The Near-to-Far test shows a similar restriction in range. At the time of the data collection we did not have measurements of nonaviator, age-matched controls. We subsequently administered these tests to nonaviator subjects and have measured durations beyond 3.0 s. Consequently, restriction of range is operative on the abscissa as well.

Difficulty of Operation Performance Measurements. Some of the correlations between the vision test performance and pilot performance were statistically significant; however, the size of these correlations was small. In other words, the vision test performance of the fighter pilots was a significant but trivial predictor of operational performance. These small, measured correlations may reflect a larger underlying correlation that is partially obscured by the variability in operational performance measures. This limitation can be addressed analytically with appropriate data and the following equation:

$$r = (r_{xy})/((r_{xx})(r_{yy}))^{0.5}$$

where r_{xy} is the uncorrected measured correlation between vision test and the aviation performance, and r_{xx} and r_{yy} are the reliability coefficients of the two measurements (17).

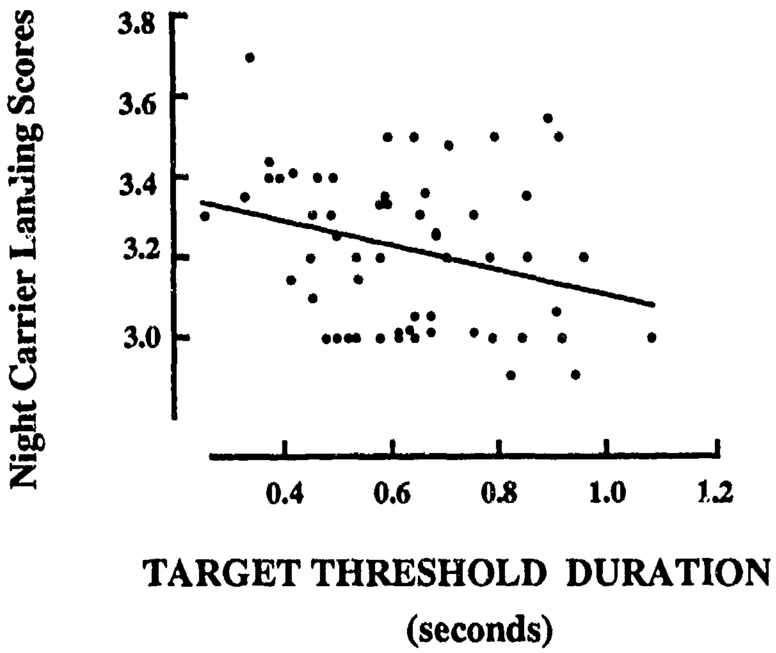

Figure 4. Example of the restriction of range of scores on actual data. The x-axis is vision test performance for which larger numbers reflect poorer performance, and the y-axis is aviation performance for which larger numbers reflect better performance. There is apparently a floor effect in that performance below 2.9 is not found.

The measured correlation between NCLS and Near-to-Far speeds is -0.29 ($p = 0.026$). This correlation indicates that there is a statistically significant inverse relationship between the vision test and NCLS; the pilots who were able to perform the vision test faster had better night carrier landings. This correlation is modest, but the above formula can be used to obtain a better estimate of the true relationship between these two variables if an estimate of the reliability of each is available.

Night carrier landing scores have a reliability of about 0.39 (Dr. Robert Kennedy, personnel communication). Unpublished data suggest a reasonable estimate of the reliability of the Near-to-Far test is at least 0.80. By substituting these values into the equation, the underlying correlation can be calculated and is of the order of -0.50. This is the value of the correlation that would have been measured had measurements been without error. Although this is a very powerful idea, it does not go beyond the limitations imposed by the range restriction.

<u>The Relativity of All Correlations</u>. A correlation is always relative to the specifics of the population sampled and to the manner in which the measurements were made. It is really quite meaningless to think of the measured correlation as indicative of some "true" correlation underlying the one that was measured (16). The measured correlations between the vision tests and the operational performance of the jet pilots do not provide an estimate of <u>the</u> underlying correlation between the operational performance and the vision skill, nor does the

measured correlation provide information concerning the magnitude of the correlation for any group except that from which the sample was drawn, Navy jet pilots. For this approach to work, what we need to know is the relationship between the vision test and operational performance measured before the subjects became aviators, then measured again after the subjects became aviators. This is exactly the information we cannot get because nonaviator subjects are not permitted to fly.

RECENT ADDITIONAL DATA RELEVANT TO THE NAS OCEANA, VA, DATA BASE.

During the analysis of the data, it became clear that assembling a comparable data base on helicopter pilots as well as age-matched college students would increase the power of the analysis of the NAS Oceana, Virginia fighter pilot data base. For example, these additional data provided us with an indication of the extent of the range restriction of the vision tests.

To date, we have completed the collection of data from helicopter pilots and college students as well as the analysis of some aspects of the data base. Because air-to-air target detection data and NCLS are available only for the jet pilots, these additional data do not resolve problems associated with operational performance measurements. These data did, however, provide insight into an alternative experimental approach that may circumvent some of the problems related to operational performance measurements. This approach provides a framework for the future direction of research on this project.

FUTURE DIRECTION OF THE RESEARCH

Theoretical Framework

The future direction of this research program was suggested by the kind of comparison illustrated in Fig. 5, which shows two frequency distributions. One distribution is the dark focus measurements obtained from 137 Navy jet pilots; the other distribution is the dark focus measurements obtained from 50 Navy helicopter pilots.

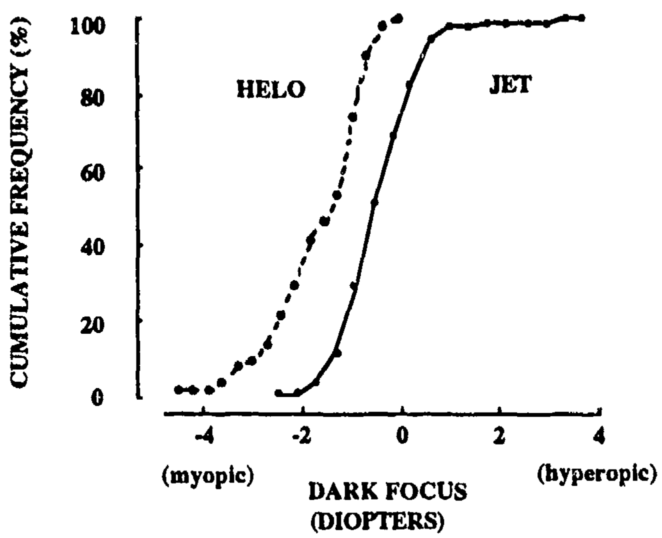

Figure 5. Two frequency distributions of vision test scores, one for jet pilots and one for helicopter pilots. The important point here is that these two distributions are different although the two groups of pilots have passed the same vision screening and were not differentiated on the basis of anything other than their aviation community and operational performance.

Dark focus is the state of accommodation the eye assumes in the dark. It can be thought of as the resting state of the accommodative system. Dark focus is most often measured in diopters. The vast majority of people are myopic or near-sighted in the dark. The measurement of dark focus is shown on the abscissa in Fig. 5. Negative values indicate a myopic or near-sighted dark focus; positive values indicate a hyperopic or far-sighted dark focus.

The difference between these two distributions is statistically significant; but more importantly, the magnitude of the difference between the two groups deserves mention. About 35% of the fighter pilots have no myopia in the dark, or are actually hyperopic in the dark (abscissa values at 0.0 or to the right of 0.0); whereas none of the helicopter pilots have such a low level of myopia in the dark. About 85% of the fighter pilots have about 1.0 diopters of myopia or less, compared to about 40% of the helicopter pilots.

In essence, these data permit us to estimate the probability of error in guessing, purely on the basis of the dark focus score alone, whether a particular subject is a helicopter or a jet pilot. These data support a signal detection decision model (18) that predicts the probabilities of errors when basing decisions on these types of distributions.

This approach can work with dark focus because it was not a criterion for assigning pilots to either the helicopter or jet communities. In other words, because all the pilots whose data are shown in Fig. 5 had completed the same vision screening, there is no *a priori* reason to expect a difference between the two distributions. Since a difference was found, the question is what caused it. Although we do not yet know what caused the difference, the difference suggests a way to proceed with the task of identifying and validating vision standards for naval aviation.

Differences in vision test performance between jet and helicopter pilots must result from factors other than those operative at initial selection. Such factors would have differential effects on each of the specific aviation communities, determining, at least in part, a pilot's continued success in that community. Dark focus must be related to some unidentified variable that had sufficient operational impact to cause a difference between the two groups.

Subsequent research can be pursued to identify how dark focus is related to the origin of the observed difference. The difference may be due to any or a combination of factors: self-selection, an unrecognized correlation to another selection criterion, differential attrition, or the acquisition of some important vision relevant skill. Depending on the research results, the observed difference may be useful for decisions concerning the assignment of pilots to different communities, or for the development of a vision training package.

These ideas can be applied directly to the question of vision standards. If tests of visual skills can be found that are independent of the Navy's current vision selection standards for aviation, then differences in the visual skill between aviators and nonaviator, age-matched control subjects must be due to factors other than vision screening during selection. These factors could be differential attrition due to poor aviation or student performance, or to the effects of training. Either way, the skill is crucial for continued survival in the aviation community. Subsequent research would be designed to identify the role that the tested vision skill played in aviation and to identify why the skill is disproportionately represented in the sample of successful aviators.

Two concepts are fundamental to this argument. The first is the proviso that the tested visual skill is independent of the Navy's current vision selection standards for aviation. The second concerns the definition of control groups. If the first concept, the proviso of independence, is not met, the selection process will skew the distribution of scores on the vision test . This may be the case with the vision test battery that was administered to the jet pilots at NAS Oceana since the Navy's current vision selection standards for aviation include standards for visual acuity and refractive error, which exclude many aviation officer candidates. Several of the tests in the vision test battery that were administered to the Navy jet pilots at Oceana, Virginia, are critically dependent on central acuity. Consequently, differences between aviators and age-matched, nonaviator control subjects may be the consequence of the Navy's current vision selection standards for aviation and may, therefore, be trivial.

There is a rich body of vision research on visual skills for which variance in visual acuity has a negligible, if any effect. The distribution of these skills within the naval aviation community should not be statistically different from the distribution in samples of age-matched, normally healthy nonaviators. If aviators and nonaviators are different, then it is only to the extent that the skill contributes to successful aviation performance.

This argument is correct if, and only if, there is no correlation between the vision skill tested and any of the current aviation selection standards. Whether or not there is a correlation with a current standard, and if so, how large, are empirical questions; the correlation can be measured and its importance identified.

Which control subjects should be used? With this approach it is more useful to think of performance norms from samples drawn from identifiably different subject groups, such as jet instructor pilots, helicopter instructor pilots, jet student pilots, helicopter student pilots, aviation officer candidates, college students, and graduates.

All the differences on a vision test found among various groups of pilots and control groups must be attributable to the effects of experience, differential attrition, or training effects. Regardless of the cause(s) of the difference(s), the skill which the vision test measures is de facto important for success as a naval aviator.

If a difference is identified, additional research will be needed to address two subsequent questions:

a. Can the difference can be attributed to training effects or not? If sizable training effects are found to be important for performance on the vision test, then a subsequent question to be addressed is whether such training may be warranted for aviation operational performance.

b. In what operational scenarios do specific vision skills play a role? The answer to this question will necessitate performance measurements and a correlational analyses of the kind conducted on the data obtained at NAS Oceana. However, the primary advantage the current approach has is that the vision skill will already have been demonstrated to be crucial for operational success, not confounded with a selection factor. In this way, the demonstration of validation would not depend on the correlation of operational and vision test performance. Furthermore, the purpose of the correlation is confirmatory, identifying the operational role and importance of the vision skill.

How To Select Vision Tests To Evaluate?

The principal question now is to identify candidate vision tests for evaluation. We will use the following criterion to select a vision test for evaluation:

a. The best evidence suggests that the vision test is not acuity limited; that is, the vision test is minimally affected by central acuity.

This criterion is important because acuity is a primary selection factor for naval aviation personnel. If the candidate vision test is heavily dependent on central visual acuity limitations, then any differences between the aviators and nonaviators may be due merely to the influence of visual acuity requirements.

b. On the basis of face validity and expert opinion, the vision test assesses a visual skill likely to relate to pilot performance. This criterion will help reduce the number of potential-candidate vision tests to be evaluated.

c. The vision test assesses skills that are minimally correlated among themselves. This criterion should help minimize the redundancy among the candidate vision tests.

d. Background information on the vision test is sufficient so that development time is minimized.

e. The test should lend itself to automated administration for routine testing of large numbers of subjects.

We anticipate using a PC-based computer graphics display system stimulus generator and experimental controller. Such a vision testing device is currently available off-the-shelf. A major advantage of this approach is that the same computer-based system would be used for the evaluation of each vision test. The most that would be required for each new test would be some software development. Because the various vision tests will use the same common hardware, the transition to a useful, field product will be simplified.

Whether or not this project proceeds to completion with a useful fielded product depends on numerous factors, including continued funding. Nevertheless, the necessary theoretical and technical framework are available.

CONCLUSIONS

The vision standards research program at the Naval Aerospace Medical Research Laboratory has provided information, insight, and understanding concerning vision and related requirements for success in Navy aviation. The specifics of much of the research conducted in support of this program are summarized in the appendix. A research plan to guide future work has been developed based on the work completed to date. Future work is designed to a) identify vision skills that contribute in an important way to success in the naval aviation operational arena, b) provide practical instruments for routine measurement of these skills in large numbers of naive subjects, and c) provide measurable vision standards that can be utilized in the selection of prospective naval aviation candidates.

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APPENDIX

Abstract summaries and reference citations to reports and publications describing the data obtained from the 175 U.S. Navy jet pilots tested at the Tactical Air Combat Training Range at NAS Oceana, Virginia.

1. Monaco, W.A. and Hamilton, P.V., "Air-to-air target detection." In *Proceedings of the Tri-Service Aeromedical Research Panel Fall Technical Meeting*, NAMRL Monograph-33, Naval Aerospace Medical Research Laboratory, Pensacola, FL, November 1984, pp. 11-17.

    The statistics of the vision test performance of 91 fighter pilots tested at NAS Oceana, Virginia, are presented. In addition, peer ranking was used to obtain a subjective score estimating target detection performance. Correlations and multiple regression analysis were computed between the vision test and operational performance scores. This preliminary analysis indicated that both high and low central acuity and lateral motion detection combined to predict target detection performance.

2. Monaco, W.A. and Hamilton, P.V., "Visual capabilities related to fighter aircrew performance in the F-14 and adversary aircraft." In *Medical Selection and Physiological Training of Future Fighter Aircrew*, Neuilly-sur-Seine, France: NATO-AGARD, AGARD Conference Proceedings No. 396, 1985, pp. 38-1 to 38-9.

    Air-to-air target detection distances of 91 U.S. Navy jet pilots measured with a computerized telemetry network during air combat maneuvers were reported. These measurements were used as the performance criterion in a stepwise multiple regression model evaluating the influence of environmental, situational, and visual factors. Some of the environmental and situational factors evaluated were type of aircraft to be detected, its size, closing velocity, sun position, acceleration forces, cloud cover, target aircraft rate of climb. The vision factors evaluated in this study were spot detection, high-contrast acuity, low-contrast acuity, low-contrast acuity in the presence of glare, accommodative flexibility (from near to far), and lateral motion detection. The multiple regression analysis indicated that air-to-air target detection performance of the pilots is determined more by the range in environmental and situational factors than by the range in visual test performance among the pilots. This is to be expected considering that Navy pilots are a highly select homogeneous group, selected on the basis of the ability to make fine discriminations with central vision.

3. Morris, A., Hamilton, P.V., Morey, W.A., and Briggs, R.P., "Vision test battery threshold and response time as predictors of air-to-air visual target acquisition in F-14 and adversary aircraft." In *Medical Selection and Physiological Training of Future Fighter Aircrew*, Neuilly-sur-Seine, France: NATO-AGARD, AGARD Conference Proceedings No. 396, 1985, pp. 39-1 to 39-8.

    The NAMRL vision test battery provides assessment of various visual functions, including spot detection, acuity at high and low contrast, glare sensitivity, and accommodative flexibility. Within these tests there are measures of threshold, threshold-stressed reaction time (for near-threshold stimuli), and unconfounded response times (for supra-threshold stimuli). The contribution of response time variables to predicting flight performance was evaluated for 73 fighter pilots. Vision test data were compared to performance in air combat maneuver training. The distance (slant range) between the observer and target aircraft at time of initial visual detection was used as the performance variable. Availability of response time variables enhanced the ability to predict the air-to-air visual target detection performance of these pilots. Four vision variables accounted for about 32% of the variance in performance of those pilots who detected target aircraft at slant ranges greater than the group average. Prediction of performances improved by incorporating other vision data and additional refinement of the performance measure.

4. Morris, A. and Hamilton, P.V., *Visual acuity and reaction time in Navy fighter pilots*, NAMRL-1324, Naval Aerospace Medical Research Laboratory, Pensacola, FL, 1986.

    Simple visual reaction time, spot detection ability, and static visual acuity under several conditions were reported and the influences of age and spectacles were examined. The average high-contrast acuity score was 0.40 min of visual angle (20/8 Snellen); no pilot had worse than 20/15 acuity. These findings together with other data suggest that Navy fighter pilots have better vision than nonaviators of the same age, and possibly better vision than student naval aviators. Correlational analysis suggests that acuity threshold, simple visual reaction time, and threshold-stressed reaction time are independent measures of visual functioning. Spectacled pilots had poorer vision than nonspectacled pilots, and older pilots tended to have poorer vision than younger pilots.

5. Hamilton, P.V. and Morris, A., *Effects of the neutral density helmet visor on the visual acuity of Navy fighter pilots.*, NAMRL-1325, Naval Aerospace Medical Research Laboratory, Pensacola, FL, 1986.

> The visual acuity of 63 Navy fighter pilots was measured under four viewing conditions of the vision test battery administered at NAS Oceana, Virginia. These and other pilots were also interviewed concerning their visor usage habits. Use of the 12% neutral density visor resulted in an average acuity loss of about 0.51 min of visual angle for low-contrast targets under high-luminance veiling glare conditions. The visor may cause an operationally significant reduction in visual acuity in the presence of luminance levels encountered at typical flight altitudes. Pilots range widely in their sensitivities to reduced contrast and glare so a single optical density visor would not be optimal for many pilots. Pilot attempts to identify individually optimal strategies for using visors and sunglasses often have no objective or systematic basis. Recommendations are presented for improving the vision of aviators wearing visors.

6. Temme, L.A. and Ricks, E., *The accommodative status in the dark of U.S. Navy fighter pilots,* NAMRL-1332, Naval Aerospace Medical Research Laboratory, Pensacola, FL, 1987.

> Visual accommodation of 172 naval aviators in the dark was measured and compared to their most recent night carrier landing scores and the average distance at which an adversary aircraft was first sighted during air combat maneuver training. No significant correlations were found between the accommodation measures and either measure of operational performance. Reasons for this result are discussed. Accommodation measures made in the aviator sample in the dark were compared to measures made in samples of college students reported in the literature. The aviator sample was significantly less myopic than the student sample. For example, only 6% of the students have as little myopia as 50% of the naval aviators. This dramatic difference in accommodation could result from either training or some set of selection factors. Possible reasons for this finding and its significance for the Navy are discussed.

7. Morris, A., Temme, L.A., and Hamilton, P.V., "What's wrong with the aviator's helmet sun visor?" *Report of the 28th meeting of the Air Standardization Coordinating Committee (ASCC) Working Party 61,* Naval Aerospace Medical Research Laboratory, Pensacola, FL, 25 April - 6 May 1988, Vol. IV, pp. M-6-1 to M-6-16.

> Many pilots use their helmet sun visor during all flying, some use it during certain flight operations, while others never use it at all. Visor wear habits and valuative comments were obtained from interviews of 126 Navy fighter pilots. Vision tests, administered concurrently with these interviews, revealed a decrease in low-contrast visual acuity in a group of 63 pilots wearing their sun visors in a glare test condition. This finding stimulated a second study investigating the effects of sun visor transmittances ranging from 50.1% to 6.3% transmission. This range includes the standard visor transmission (12%). With realistic daytime luminances (6870 cd/m^2), low-contrast spot detection, low-contrast visual acuity, and contrast sensitivity were measured with subjects viewing through filters of five different transmissions. Results of these investigations are reported and their implications discussed for the optimization of visual performance through a sun visor.

8. Temme, L.A., Ricks, E., and Morris, A., "Dark focus measured in Navy jet tactical fighter pilots." *Aviation, Space, and Environmental Medicine*, Vol. 59, pp. 138- 41, 1988.

> Visual accommodation was measured with the laser-Badal optometer in 98 U.S. Navy fighter pilots who were in a dark environment without visual stimuli. The average dark focus of the pilots was 0.25 diopters of myopia; 40% were either emmetropic or hyperopic in the dark. Only 4% had as much dark myopia as 50% of a sample of 220 college students. Although the jet fighter pilots, as a population, differed from college students in terms of dark focus, it remains to be determined whether the remarkable dark focus of the pilots was a function of training or selection. The dark focus measurements of the pilots were compared to their mean night carrier landing scores and their mean target detection slant range scores--the distance at which an adversary aircraft is first sighted during an air combat maneuver training engagement. Neither the night carrier landing scores nor the target detection slant ranges scores correlated significantly with dark focus measurements.

9. Temme, L.A. and Morris, A., "The speed of accommodation and age." *Optometry and Vision Science*, Vol. 66, pp. 106 -112, 1989.

The time needed to change accommodation from a near to a far target or from a far to a near target (0.457 and 5.486 m, respectively) was measured with a psychophysical threshold procedure in 65 U.S. Navy fighter pilots. The speed of accommodative change, far-to-near (FN) slowed with age in a statistically significant fashion; however, near-to-far (NF) did not appreciably slow with age. The intrasubject variability was greater FN than NF but did not depend on age.

10. Morris, A. and Temme, L.A., "The time required for U.S. Navy fighter pilots to shift gaze and identify near and far targets." *Aviation, Space, and Environmental Medicine*, Vol. 60, pp. 1085-9, 1989.

The speed with which 163 U.S. Navy fighter pilots can shift their line of sight and discriminate high-contrast acuity targets was measured. The targets were simultaneously projected onto two screens: one at 18 feet and one at 18 inches in front of the subject's eyes. Subjects were required to fixate first one screen and then as rapidly as possible, shift gaze to the other screen. The minimum exposure duration required to correctly resolve both targets was measured. For 65 subjects, the test targets was 1.0 min of visual angle; for 98 subjects the target was 2.0 min of visual angle. The major findings were 1) both far-to-near and near-to-far mean times significantly slowed with age; 2) the far-to-near and the near-to-far mean times were not significantly different with the oldest subject (44 years of age) excluded; 3) the within-subject standard deviation far-to-near increased with age and was significantly greater than the near-to-far standard deviation, which did not increase with age; 4) there was a significant correlation between the mean near-to-far speeds and the night carrier landing performance of the aviators.

11. Temme, L.A., Ricks, E., Morris, A. and Sherry, D., "Visual contrast sensitivity of U.S. Navy jet pilots." *Aviation, Space, and Environmental Medicine*, Vol. 62, pp. 1032-6, 1991.

Good visual contrast sensitivity (CS) is often described as a visual capability important for success as a military aviator and so has been suggested as a physical standard for personnel selection and retention. To evaluate this idea, we measured and compared the CS of 135 U.S. Navy fighter pilots ranging in age from 24 to 44 years (mean = 30.20, S.D. = 4.06) to the CS of nonaviators. We obtained the nonaviator data from published studies of other investigators who used similar procedures with the same, widely used commercially available apparatus (Nicolet CST 2000). In addition to this comparison, we correlated the pilots' CS with their air-to-air target detection distances measured during air combat maneuver training and to their night carrier landing performance scores. The major findings were 1) the mean CS of the aviators and the nonaviators were within ±1.0 S.D. of each other in most instances, and those few instances where a greater difference was found were parsimoniously explained by methodological and procedural factors; 2) sensitivities to different spatial frequencies were highly correlated among themselves, indicating a large amount of redundancy among the measurements, and 3) there was no evidence of a relationship between CS and air-to-air target detection distances or night carrier landing performance.

12. Morris, A., Temme, L.A., and Hamilton, P.V., "Visual acuity of the U.S. Navy jet pilot and the use of the helmet sun visor." *Aviation, Space, and Environmental Medicine*, Vol. 62, pp. 715-21, 1991.

Visor wear habits, valuative comments, and vision test data were obtained from interviews of 126 Navy fighter pilots. The interviews revealed that many pilots use their helmet sun visor whenever they fly, some use it only during certain flight operations, and others never use it. Study 1 (conducted at 343 cd/m^2) revealed a decrease in low-contrast visual acuity attributable to helmet sun visor use in the presence of a glare source. These findings prompted a second study of the visual effects of visor transmittance. Low-contrast spot detection, acuity, and contrast sensitivity were measured at an operationally realistic daytime illumination level (6870 cd/m^2) in subjects viewing through filters ranging from 6.3 to 50.1% transmission. (Standard visor transmission is 12 ± 4%). Results showed that filter density, and consequently the illuminance reaching the eyes, could be varied over a wide range without critically affecting these visual functions. Prevailing environmental illuminance should be considered when selecting sun visors or sunglasses. These results have implications for optimizing visual performance through visors.

13. Temme, L.A. and Still, D.L., "Prescriptive eyeglass use by U.S. Navy jet pilots: Effects on air-to-air target detection." *Aviation, Space, and Environmental Medicine,* Vol. 62, pp. 823-6, 1991.

Air-to-air target detection distances, age, career jet flight hours, and total career flight hours were obtained for 167 U.S. Navy fighter pilots participating in air combat maneuver training at NAS, Oceana, Virginia. Of the pilots sampled, 22 used a prescribed spectacle correction while flying, 145 did not. This paper compares the air-to-air target detection distances between the two groups of pilots, those with corrective glasses and those without. Sunglasses and tinted filters were not factors in the present study. The results strongly suggest that, as a group, the pilots without glasses were able to detect targets at a greater distance than the pilots with glasses. When the pilots were matched on the basis of age and flight experience, the difference in air-to-air target detection capabilities of the two groups increased. The pilots without glasses were able to detect their adversary at a distance more than 20% farther than the pilots with glasses.

14. Still, D.L. and Temme, L.A., "Eyeglass use by U.S. Navy jet pilots: Effects on night carrier landing performance." *Aviation, Space, and Environmental Medicine,* Vol. 63, pp. 273-5, 1992.

Night carrier landing scores (NCLS), age, career jet flight hours, and total career flight hours were obtained for 167 U.S. Navy fighter pilots participating in air combat maneuver training at NAS, Oceana, Virginia. Of the pilots with NCLS, 16 used a prescribed spectacle correction while flying, 106 did not. This study compared the NCLS of the two groups of pilots, those with glasses and those without. We found no significant difference in NCLS between the two groups of pilots --- even when the pilots were matched on the basis of age and flight experience.

15. Temme, L.A., *The detection of lateral motion by U.S. Navy jet pilots,* NAMRL-1368, Naval Aerospace Medical Research Laboratory Report, Pensacola, FL, 1992.

The leftward and rightward threshold velocities of a small spot of light presented in an essentially empty visual field were measured in 110 U.S. Navy jet pilots. These measurements were compared to similar measurements made in nonaviator subjects as reported in the published literature. We found no evidence that the pilots and nonpilots differed, although there was only a small sample of subjects available from the literature. Air-to-air target detection distances measured during air combat maneuver training were compared to the aviators' velocity thresholds. The statistical evidence of a relationship between the vision and the performance measures was ambiguous, and additional data would be necessary to evaluate this relationship. The correlation between the age of the pilots and their velocity thresholds was not statistically significant. This particular test of lateral motion holds little promise as a useful, practical tool for personnel selection and retention and does not warrant further investigation for this purpose.

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13. ABSTRACT (*Maximum 200 words*)

The Naval Aerospace Medical Research Laboratory (NAMRL) has been pursuing a research program to develop easily administered tests of vision skills that are valid, practical tools for the selection of personnel likely to be successful in the naval aviation arena. From 1980 to 1985, NAMRL maintained a data collection effort measuring the vision of U.S. Navy fighter pilots assigned to the air-to-air combat training range (NAS Oceana, VA). Both operational performance and vision test data were collected from the pilots. This report presents a) the underlying theoretical orientation that guided that research effort, b) a summary of the research results to date, and c) the ideas guiding the design of the research strategy projected for the future. For convenience, abstracts of the principle publications describing this work are assembled in the appendix.

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