A COMPARATIVE STUDY OF VISUAL PERFORMANCE IN JET FIGHTER PILOTS AND NON-PILOTS

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ABSTRACT

Thirty jet fighter pilots from the Oregon Air National Guard, and 30 age- and gender-matched health profession students were tested for visual performance in dynamic visual acuity (DVA), contrast sensitivity (CS), reaction time (RxT), motor response time (MRT), and response time (RpT). DVA was assessed using a Keystone Kirshner Rotator with a projected Landolt 'C'. CS was measured with the Vistech Vision Contrast Test System. RxT, MRT, and RpT were measured using the Reaction Plus device. For all visual abilities tested except MRT, pilots performed at a significantly ($p<.05$) higher level than did the students. Mean DVA was 32.3°/sec. for pilots and 25.3°/sec. for students. Pilots' CS was significantly better than students at all but the lowest spatial frequency tested. Both RxT and RpT were significantly better for pilots with a mean pilot RxT of .23 sec. and mean student RxT of .26 sec. The mean RpT for pilots was .35 sec. and mean RpT for students was .39 sec.

KEY WORDS

dynamic visual acuity, reaction time, response time, contrast sensitivity, pilots

Fighter pilots perform in an environment unlike any other occupation. During low-altitude high-speed flying the pilot is required to monitor a vast array of complex control panels while simultaneously noticing and identifying outside visual stimuli. Added to this are high-speed gravity force (G) maneuvers when trying to locate simulated attacking enemy aircraft. Modern day fighter aircraft are capable of speeds in excess of Mach 2.0 and produce loads of 8-9 G's. Flying in this environment requires the pilot to perform a multitude of visual and integrative functions. Because of continuous exposure to these extreme environments, pilots may undergo some visual adaptations, specifically in the areas of dynamic visual acuity (DVA), contrast sensitivity (CS), and reaction, motor response, and total response times (RxT, MRT, and RpT).

The potential relationship between DVA and pilot performance has been of interest to the military for nearly four decades. The early work of Ludvigh and Miller[1] at the Pensacola Naval Aerospace Medical Research Laboratory is still widely cited. Several follow-up studies suggesting continuing military interest in DVA are also available.[2-4] However, there has been much less attention given to contrast sensitivity and reaction/response times among jet fighter pilots. Both DVA and CS have been identified as promising areas for future research in the area of human visual performance.[5]

METHODS

Subjects

Thirty fighter pilots from the 123rd Fighter Interceptor Squadron, Oregon Air National Guard, Portland International Airport, Portland, Oregon, were tested for DVA, CS, RxT, MRT and RpT. Their results were compared to those of a sample composed of 30 age and gender-matched graduate students in the health professions. Subjects ranged in age from 21 to 38 years and exhibited habitual 6 m and 40 cm visual acuity of 20/20 or better for each eye, a minimum stereoacuity of 40" as tested by the Randot circle stereoacuity test,[a] and no ocular pathology.

Procedures

All visual performance testing was conducted in accordance with the protocols of the Pacific Sports Visual Performance Profile (PSVPP), a norm-referenced standardized testing battery developed for use in the visual evaluation of elite athletes.[6] The PSVPP protocols were used for testing athletes at the 1985 National Sports Festival and the 1986 U.S. Olympic Festival, and are used routinely for visual performance assessment of athletes in the United States, Canada and Europe. Unpublished normative data for the PSVPP have also been acquired for samples of non-athlete young adults and adults over the age of 50 years.

- *Dynamic Visual Acuity (DVA)*

DVA was tested using the Keystone Kirshner Rotator[b] (a variable speed rotating mirror device no longer available), an AO Project- O-Chart, and a standard wall mount screen. A Landolt 'C' was used as the target. The Project-O-Chart, rotating mirror, and screen were aligned such that the projected Landolt 'C' moved in a clockwise circle of 55 cm diameter. The Landolt 'C' subtended 10 min. arc (20/40) at the 3 m test distance. Ambient illumination at the screen was kept at 6-7 foot-candles. Subjects stood in a comfortable position and were instructed to hold their heads stationary during testing.

The Landolt 'C' was initially viewed rotating on the screen at a velocity of 53.3°/sec. (100 rpm). The subject was instructed to, "Watch the rotating letter on the screen and call its direction (left, right, up or down) as soon as you can see it." The velocity of the target was gradually reduced at the rate of 2.4°/sec./sec. (4-5 rpm/sec.). For each subject the rpm at which the orientation of the Landolt 'C' was identified was recorded for each of three trials and later converted to angular velocity in °/sec. for analysis.

- *Contrast Sensitivity (CS)*

CS was tested using the Vistech VCTS 6500 wall chart Contrast Sensitivity Test System[a] (Figure 1). The Vistech chart consists of five rows of nine circular targets each. The spatial frequencies tested ranged from 1.5 cpd in Row A to 18 cpd in Row E. Contrast sensitivity demand varies from 3 to 170 in Row A (1.5 cpd), 4 to 220 in Row B (3 cpd), 5 to 260 in Row C (12 cpd), 5 to 170 in Row D (12 cpd), and 4 to 90 in Row E (18 cpd).

Subjects were situated 3 m from the chart, standing in a comfortable position. All testing was performed binocularly. Illumination was calibrated using the Vistech photometric system. For each of the five rows, the subject's last correctly called target was recorded. Target number was then converted to actual contrast sensitivity for analysis.

- *Reaction (RxT), Motor Response (MRT) and Response Times (RpT)*

The Reaction Plus[c] dual chronometer device was used to assess visual motor reaction and response times to a central visual stimulus based upon visually

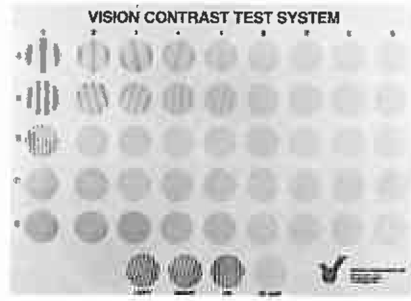

Figure 1.

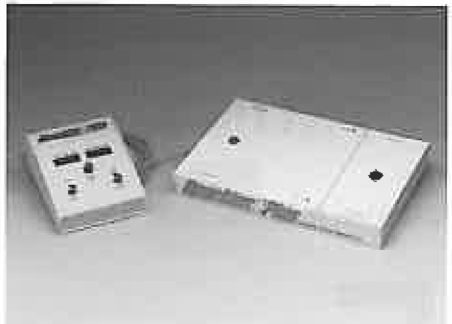

Figure 2.

guided eye-hand motor response (via hand button release and immediate depression of a lit target button).

The Reaction Plus device (Figure 2) measures 42.5 cm x 27.5 cm in size and includes a ready light, reaction button, and stimulus/response button. The reaction and response buttons are separated by 30 cm. Testing was accomplished in the following manner:

The subject stood over the Reaction Plus device. The device was positioned 34" above floor level with illumination at 6-7 foot-candles measured at the instrument's surface. The subject placed his dominant hand on the reaction button such that the hand was lined up tangent to the boundary line with the reaction button positioned under the flat of the hand at the base of the fingers. The subject's head was aligned vertically over the stimulus-response button. The tester, with control panel, was screened from the subject's view.

Once aligned, the subject was given the following instructional set: "I will say 'Ready'...and within one to five seconds the response button will light. When this happens move your hand as quickly as possible from the reaction to the response button." The examiner then initiated the stimulus (from the control panel) between two and four seconds following the "Ready" command. Each subject was given two practice trials. Subjects were not told their times during the testing sequence. Scores for each of five successive trials were recorded.

We conceptualize reaction time (RxT) as the period during which the stimulus is processed prior to the initiation of the motor response. Operationally, it is the time from the lighting of the response button to the time the subject lifts his hand from the reaction button. Response time (RpT) is the RxT plus the time it takes the subject to make an accurate hand movement from the reaction button to the illuminated response button. Motor response time (MRT) is the difference between RpT and RxT; operationally, it is the time it takes the subject to move his hand from the response to the reaction button.

- *Data Analysis*

Mean scores from each of the tests were compared between the two groups of subjects using an unpaired, two-tailed t-test. Means for the multiple measures of DVA and the reaction/response time variables for each subject were calculated prior to analysis; these mean values were evaluated between groups using the t-test.

RESULTS

- *Dynamic Visual Acuity (DVA)*

Pilots were able to accurately perceive detail in the moving target at a significantly higher velocity ($p<0.05$) than were students (see Table 1). Mean pilot DVA was 32.3°/sec.(60.6 rpm) with a standard deviation of 5.3°/sec.(10.0 rpm). Mean student DVA was 25.3°/sec. (47.5 rpm) with a standard deviation of 3.6°/sec.(6.7 rpm).

- *Contrast Sensitivity (CS)*

CS of pilots was compared to that of students at each spatial frequency tested using an unpaired t-test. Mean pilot CS was found to be significantly better ($p<0.05$) than students for all spatial frequencies tested except the lowest (1.5 cpd). CS data for both the pilot and student groups are presented in graphical and tabular form (see Figure 3 and Table 1). As can be seen, CS for both pilots and students is close to the 95th percentile based on reported expecteds furnished by Vistech. It can also be seen that the CS of pilots is superior to that of students at all but the lowest spatial frequency tested.

Table 1
Descriptive Data

		Pilot		Student	
		$\bar{X}$	S.D.	$\bar{X}$	S.D
DVA (°/sec.)	Dynamic Visual Acuity	32.3	5.3	25.3	3.6
RxT (sec.)	Reaction Time	0.23	0.02	0.25	0.02
MRT (sec.)	Motor Response Time	0.12	0.02	0.14	0.06
RpT (sec.)	Response Time	0.35	0.03	0.39	0.06
Contrast Sensitivity					
1.5 cpd		98.3	31.3	95.5	35.6
3 cpd		178.3	18.9	143	50.1
6 cpd		191.5	36	162	60.6
12 cpd		127.3	38.5	91.9	32.2
18 cpd		51.9	18.6	31.9	18.9

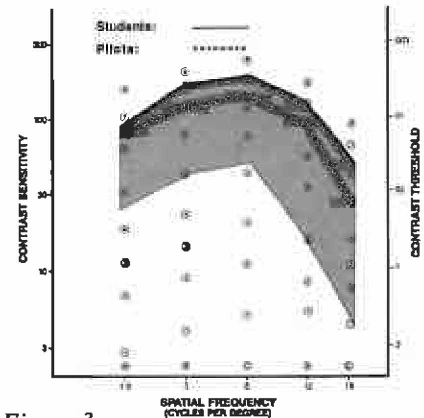

Figure 3.

- *Reaction (RxT), Motor Response (MRT) and Response Times (RpT)*

Mean pilot RxT was 0.23 sec. with a standard deviation of 0.02 sec. Mean student RxT was 0.25 sec. with a standard deviation of 0.02 sec. Mean pilot MRT was 0.12 sec. with a standard deviation of 0.02 sec. Mean student MRT was 0.14 sec. with a standard deviation of 0.06 sec. Mean pilot RpT was 0.35 sec. with a standard deviation of 0.03 sec. Mean student RpT was 0.39 sec. with a standard deviation of 0.06 sec. (see Table 1). For both RxT and RpT pilots performed at a significantly faster ($p<0.05$) rate than did students. There was no significant difference in MRT between pilots and students.

DISCUSSION

Based upon these results, it is evident that jet fighter pilots perform at a higher level than do age- and gender-matched graduate students in dynamic visual acuity, visual reaction and total response times, and contrast sensitivity at all but the lowest spatial frequency (1.5 cpd) tested.

It is our hypothesis that much of this superior performance by fighter pilots is attributable to a training effect produced by the flight training these pilots undergo, and the continuous exposure to a high velocity environment. Successful adaptation to this environment would appear to require the development of superior dynamic visual acuity, quick reaction and response to visual stimuli, and acute contrast sensitivity at the higher spatial frequencies. The day-to-day visual task demands of the jet fighter pilot (see Appendix) are quite unlike those faced by the average person. The pilot's tasks involve complex visual information processing challenges with grave consequences for visual judgment errors. These tasks include such activities as take-offs and landings at speeds in excess of 180 mph, high-speed formation flying with distances as little as 2-3 m between accompanying aircraft, and simulated air-to-air combat which involves visual localization of small targets against complex backgrounds while the plane and pilot are moving at very high speeds and often performing aerial maneuvers.

Repetitive exposure to the pilot's flight environment constitutes a stimulus for refinement and enhancement of the visual abilities which are necessary to carry out the pilot's tasks. It has been reported that each of the visual abilities examined in this study are amenable to training to higher functional levels.[7-11] Further, measurable training effects can be attained in the relatively safe confines of the laboratory, using subjects who typically bring a lower level of motivation to the task than does the jet fighter pilot as he enters his aircraft. DVA,[7-9] RxT, MRT, RpT,[10] and CS[11] have all been shown to improve by application of various training procedures over relatively brief training periods (two-six weeks).

In addition to the effects described here, heightened visual performance ability among jet fighter pilots has recently been reported for tasks involving eye movement accuracy.[12] Other individuals who are exposed to high velocity environments and programs of intense physical training have also been reported to have superior visual performance. Elite athletes who have been evaluated using the PSVPP protocols employed in this study demonstrate better CS than do non-athletes,[13] and also demonstrate RxT, MRT, and RpT which are similar to the values for the jet pilots.[6] Informal comparison of the data from the jet pilots and elite athletes indicates better performance by the jet pilots on DVA, CS and MRT. RpT is identical for the two groups, while the younger sample of elite athletes showed slightly better RxT. The apparent differences between the two groups might be explained by the more demanding environment faced by the pilots, and the greater cost to the pilots of visual errors.

The question of whether pilots' superior performance is due to some innate or previously developed ability which they possessed prior to becoming a jet fighter pilot, or due to the development of these abilities in their work environment, cannot be answered by this study. Pre-flight-school vision examinations do not test for DVA, CS, RxT or RpT. Thus, this population is not evaluated or chosen based on any of the visual abilities we have assessed. We do know that this population has been exposed to a variety of situations which place extreme demands on visual performance, and that the visual abilities measured in this study are amenable to training.

Future studies should investigate whether those chosen for flight school have visual abilities different from the general population. It would also be of interest to investigate whether performance on these measures is related to the visual demands of flying a jet fighter. If, in fact, it can be shown that DVA, RxT, MRT, RpT, and/or CS can be improved by activities involved in flying a jet, specific vision training activities can be devised to accelerate the acquisition of superior visual skills.

SOURCES

a. The Randot stereoacuity test and the Vistech 6500 Contrast Sensitivity Wall Chart Test System are available from:
Stereo Optical Company, Inc.
3539 N. Kenton Avenue
Chicago, IL 60641
(800) 344-9500

b. The Kirshner Rotator is no longer available. A similar device is available from:
W. R. Medical Electronics Co.
123 N. Second Street
Stillwater, MN 55082
(612) 430-1200

c. The Reaction Plus device is available from W. R. Medical Electronics Co., above.

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APPENDIX

1. Jet take-offs and landings involve visual tracking skills while moving at speeds in excess of 180 mph.
2. Low-level high-speed flying, often at speeds in excess of 500 knots and at levels below 100 ft., requires precise visual tracking skills.
3. Air-to-air gunnery exercises require pilots to shoot at and hit small drone targets towed by other jets at high speeds.
4. Mock air-to-air combat involves high G aerial maneuvers while visually tracking other high velocity targets.
5. Formation flying, while at high speeds at distances of 2 to 3 m from accompanying aircraft, requires fine eye-hand coordination and superior response and reaction time.
6. Air combat tactics (ACT), or aerial "dog fighting," requires precise eye-hand coordination. Fractions of a second when traveling at the speed of sound can mean the difference between life and death to the fighter pilot.
7. Instrument flying requires continuous monitoring and cross-checking of a variety of instruments, and the ability to respond in quick, accurate fine motor adjustments.
8. Air-to-air combat not only involves superior visual tracking ability and fine eye-hand coordination, but requires the ability to locate targets. Early visual contact is important for success to the fighter pilot, and is dependent upon the ability to differentiate small visual targets against highly variable backgrounds.

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