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EFFECTS OF BIFOCAL AND PROGRESSIVE-ADDITION CORRECTIVE LENSES ON AVIATOR TARGET-DETECTION PERFORMANCE

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ABSTRACT

The objective of this project was to determine if the type of presbyopic correction worn by aviators, conventional bifocal versus progressive-addition lenses (PALs), differentially affects aviator visual search performance. Experienced aviators with tactical fighter aircraft experience searched for high-contrast targets under simulated dawn/dust lighting conditions while wearing either a standard bifocal (ST-25) or PAL spectacle correction. Latency of locating high-contrast targets under these viewing conditions was affected differentially by the type of presbyopic correction used. Specifically, compared to a standard bifocal (ST-25), a PAL correction (Varilux Infinity) significantly lowered the time needed to locate static targets at a cockpit-instrument viewing distance (83 cm). Accuracy of target-location responses was not affected by the type of correction used. In addition, 7 months post experiment, 7 of the 12 participants (58%) indicated that they used their PAL correction exclusively when flying the T-39 Sabre Liner. Three subjects (25%) used their PAL correction intermittently (primarily at night) when flying, and two subjects preferred not to use the PALs. These results suggest that a) relative to bifocals, speed of responding to static targets at intermediate viewing distances may be improved by wearing PALs; and b) subjects were able to adapt to PAL lenses quickly in a laboratory setting, using them later in a functional aviation environment.

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INTRODUCTION

The objective of this project was to determine if the type of presbyopic correction worn by aviators, conventional bifocal versus progressive-addition lenses (PALs), differentially affects aviator visual search performance. Human performance data, such as speed and accuracy of target detection/identification, provide additional objective measures for use in assessing the suitability of progressive addition lenses to an aviation environment. Of course, human performance data should not be viewed in isolation of other salient issues such as modulation transfer, human factors (including spectacle-induced head movement), and patient adaptability to inherent PAL astigmatism.

Beginning as early as age 40, aviators become presbyopic, as does the vast majority of the population (7). Three to four percent of U.S. Navy pilots (M. Mittelman, personal communication, February 1993) and 12.4% of U.S. Air Force pilots (20) are presbyopic and require a multifocal-spectacle correction such as bifocals. One would expect the percentage of bifocal wearers to be even greater for aviators in the reserve forces as the average-age of reserve aviators is greater than that of active duty aviators (18). The underlying causes of presbyopia (conceptualized as an age-dependent loss of ocular accommodative ability) remains unclear (3, 4, 13). Possible causes include, but are not limited to, a) changes in the elastic properties of the lens (8, 23, 24), b) liquification of the vitreous (5), c) alterations in anterior segment geometry (10, 14-16, 21), and d) a combination of lens growth and concomitant anterior chamber shallowing (17).

Bifocals, and rarely trifocals, are authorized by the USAF and Navy as an acceptable correction for presbyopic aviators. Aviators are required to view critical information at a minimum of three accommodation distances (approach plate, cockpit instruments, and infinity). Bifocals, however, have only 2 focal lengths; 20 feet (infinity) and, usually, 40 cm, a fairly standard reading distance. Trifocals offer correction for three viewing distances, but have an unacceptably small intermediate segment, which prevents a full view of the cockpit instruments. In addition, some pilots are uncomfortable with the head movements needed to accommodate changes in focal length when wearing multifocal lenses. These conditions have created, a) a reluctance in pilots to wear presbyopic corrective eyewear, and b) potential flight hazards associated with inefficient or difficult vision. Progressive addition lenses overcome *some* of the inherent shortcomings of many bifocal and trifocal lenses, but not without tradeoffs. For example, compared to a bifocal correction, PALs increase the zone of near and intermediate correction and eliminate visible lines in the lens (see Fig. 1). This intermediate zone of changing power (clear area in PAL lens, Fig. 1), is referred to as the *transition channel*. The sphericity of the lens is maintained in this region resulting in high-quality image modulation. However, outside the transition zone (shaded area in PAL lens, Fig. 1), image quality suffers because of unavoidable spherical aberrations. The *add power* of the correction combined with the lens *manufacturing technique* determine the extent of the transition zone and the magnitude of peripheral aberrations (see Fig. 2).

Few studies have examined the human performance of subjects wearing a PAL correction for presbyopia. Previous research comparing PAL wearers to nonpresbyopic or multifocal controls (i.e., bifocal or trifocal wearers) in simple target detection (1, 2, 22) and reading tasks (12), suggests 5, that for near vision (≈40 cm):

1. Compared to prepresbyope controls, presbyopes wearing PALs have a normal *rang of eye movements* during simple target detection.

2. *Peripheral target detection* time is no different between *practiced* PAL and trifocal wearers.

3. *Adaptation* to PALs may involve a combination of anticipatory head movements, adjustments in saccadic gain, and acquisition of visual cues from a slightly blurred retinal image. These aspects of eye-head coordination *may* be fundamentally different for PAL and nonPAL wearers.

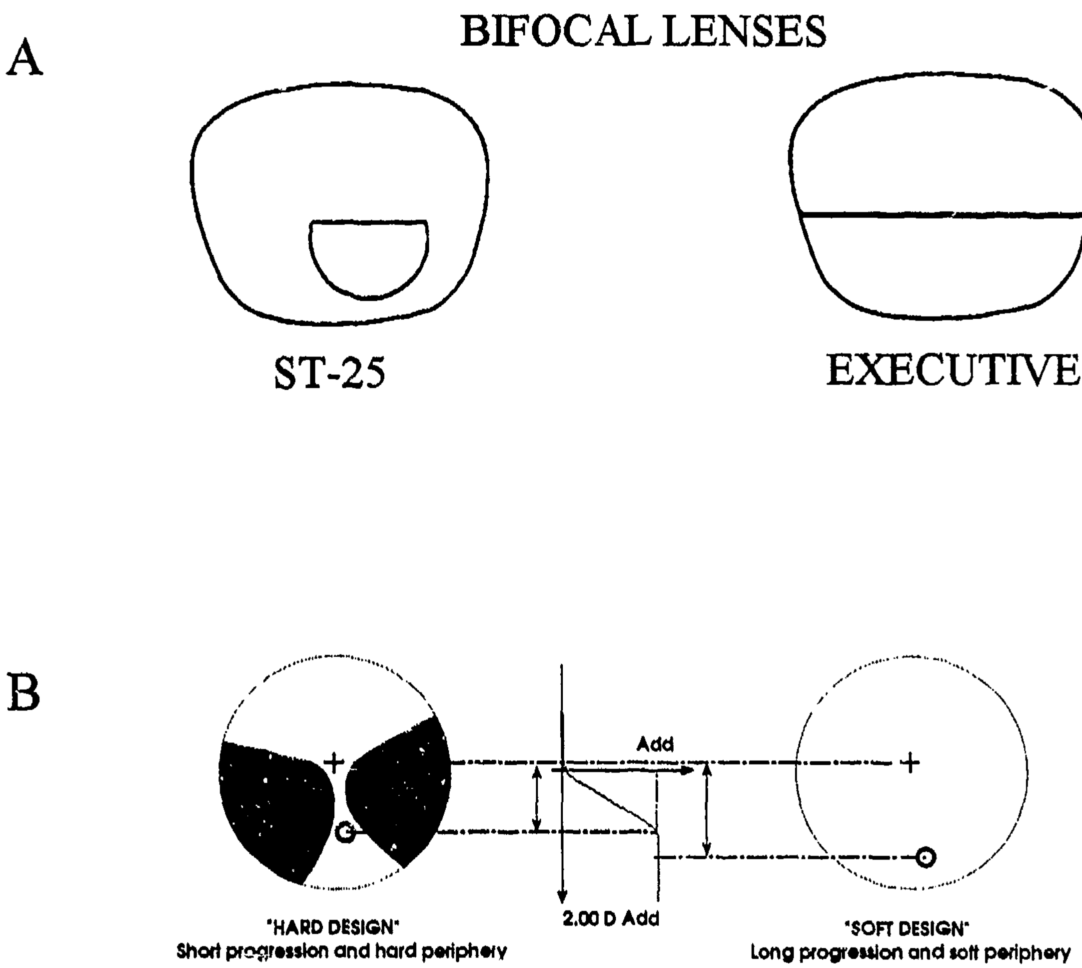

Figure 1. Comparing bifocals and PALs. A. From "Prescribing Spectacles for Aviators: USAF Experience" by R. E. Miller et al., 1992, *Aviation, Space, and Environmental Medicine, 1*, p. 82. Copyright 1992 by the Aerospace Medical Association. Adapted by permission. B. From "Progressive Lens Design: Not Hard, Not Soft, But Multi-Design" by D. Meslin, *Varilux Practice Report #1*. Copyright 1992 by the Varilux Corporation, Oldsmar, FL. Adapted by permission.

4. *Reading rate*, reading comprehension, and eye movements associated with reading have been observed to be the same for bifocal and PAL wearers.

5. Normal *head movement* is induced for targets < ±7° from central fixation for PAL wearers versus ±8.5° for bifocal wearers.

Airline pilots have given PALs favorable ratings, however the only study to address the effects of progressive lenses on pilot performance did not use objective measures and did not employ a bifocal or 20/20

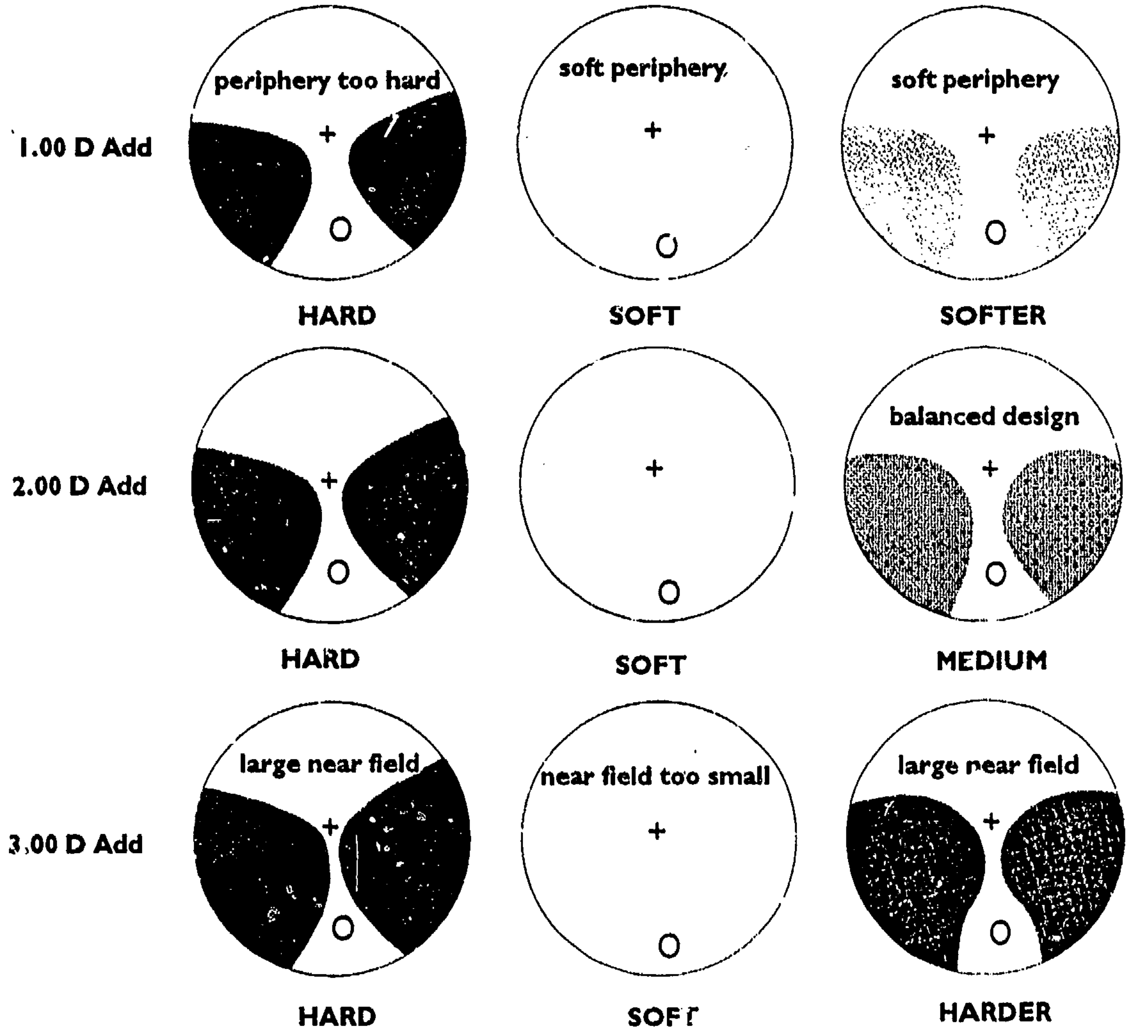

Figure 2. Comparative PAL designs as a function of add power. From "Progressive Lens Design: Not Hard, Not Soft, But Multi-Design" by D. Meslin, *Varilux Practice Report #1*. Copyright 1992 by the Varilux Corporation, Oldsmar, FL. Adapted by permission.

control group (6). If progressive lenses improve some aspects of aviator performance relative to bifocals (e.g., speed and accuracy of target detection), then the naval flight community may want to conduct a comprehensive and objective investigation of their adaptability to an aeronautical environment compared to other types of presbyopic correction.

The present study was designed to compare bifocal and PAL corrections for presbyopia using a target-detection task and three accommodation distances common to the cockpit environment. Speed and accuracy of target detection for both types of presbyopic corrections were compared.

METHODS

SUBJECTS

One active duty and 11 retired naval aviators participated in this study. The age of subjects ranged from 43 to 60 years (*M* = 53.3, *SD* = 5.2). All members of the retired naval aviator group currently fly T-39 Sabre Liners. Ten subjects reported their total logged flight hours, which ranged from 4000 to 11,500 (*M* = 8970, *SD* = 2439). Ten of the retired aviators had piloted tactical fighter aircraft.

Each subject was given a complete ophthalmological examination at the Naval Aerospace and Operational Medical Institute (NAMI). Only subjects showing presbyopia that would normally be corrected with bifocal lenses were considered for participation. Because lens opacity (the clarity of an eye's lens) may cause decrements in visual performance independent of visual acuity (11), the clarity of the lens in both eyes of each subject was assessed beforehand using an Opacity Lensmeter (model 701: Interzeag AG; Schlieren, Switzerland). None of the subjects showed signs of pathological opacity of the lens.

APPARATUS

Cockpit environment. Subjects participated while seated in an A/4 ejection seat located behind an F/15 aircraft windscreen assembly. These apparatus were located in a separate room, isolated from the experimenters and data-collection equipment. Subjects were monitored by closed-circuit television. An automated intercom system near the cockpit allowed the experimenter to maintain voice contact with the subject at all times. Ambient lighting was limited to the projection system and video monitors. Mesopic light levels (≈ 3 cd/m²) were maintained.

Visual stimulus array. Subjects viewed computer-generated, visual stimulus arrays (see Fig. 3) projected at three distances within their forward line of sight. Each projected display consisted of 119 randomly placed distractor rectangles and one target rectangle (60% the size of the distractors). This computer-generated visual array was converted to an analog video signal and a) rear-projected onto a diffused projection screen, using a High Resolution, High Brightness Monochrome Projection Monitor (model 38-B02503-71, Electrohome Limited, Ontario, Canada) placed 280 cm from the subject, and outside the canopy or b) displayed on a 30.5-cm video monitor, Sony (model PUM-1271Q), placed 83 cm in front of the subject, or c) displayed on a 22.8-cm video monitor, Burle (model TC1910A), placed 40 cm in front of the subject. The 30.5- and 22.8-cm video monitors were located inside the windscreen assembly (15° to the left and right, respectively, of the subjects forward line of sight).

Forty unique visual arrays were generated, each containing one target. A small crosshair was located at the center of each display, dividing the display into four equal quadrants. Targets occurred equally often in each of the four quadrants at each of five eccentricities (1, 2.4, 3.8, 4.3, and 5.3°) measured from the center of the display. In one experimental session, each visual array was presented randomly once on each visual display device (VDD: back-projection screen, 22.8-, or 30.5-cm video monitor). Only one VDD was illuminated at any one time. In addition, visual arrays were never displayed successively on the same VDD, thus forcing the subject to accommodate to a new focal distance to view each successive visual array. Subjects viewed 120 visual arrays in a single experimental session.

A Pritchard Photometer with 6' arc aperture (model PR-1980A, Photo Research, Burbank, CA) was used to measure the luminance of a) each target rectangle, b) the distractor rectangle nearest the target, and c) the background midway between the target and its closest distractor. These measurements were made for visual arrays appearing on the rear-projection screen and both video monitors and were used to compute target-background and distractor-background brightness contrast $[(L_{Max} - L_{Min})/(L_{Max} + L_{Min})]$. Target-background and distractor-background brightness contrast (*M* = 0.72, *SEM* = 0.01; *M* = 0.74,

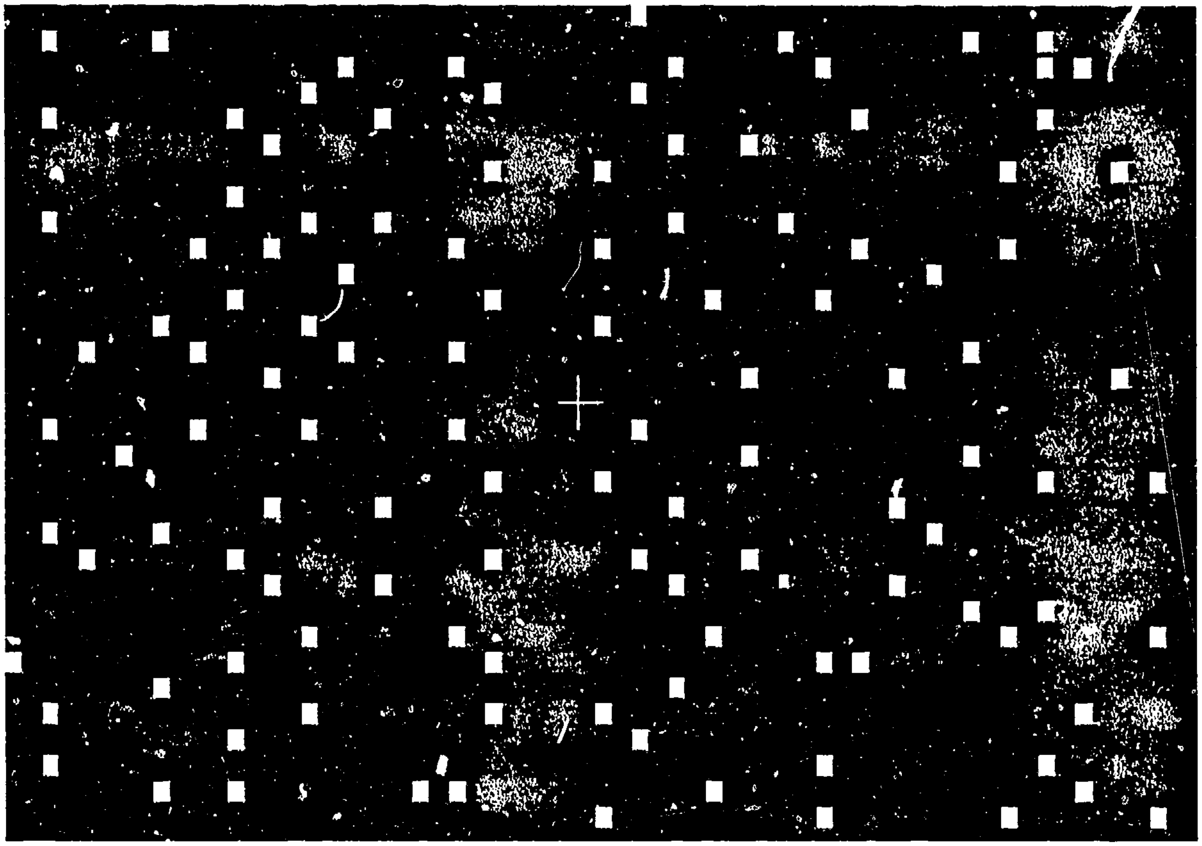

Figure 3. Example of a visual display with 119 distractor rectangles and 1 target rectangle.

SEM = 0.01, respectively) was constant across the three VDDs. The overall luminance of the rear-projection screen, and the 30.5- and 22.8-cm video monitors was approximately equal (2.99, 2.87, and 3.07 cd/m², respectively).

Experimental control and data acquisition. Experimental control and data acquisition were under microcomputer control (Compaq Deskpro 386/20, model 60). An analog-to-digital I/O board (model DASCON-1, Metrabyte Corporation, Taunton, MA), multifunction timer (model CTM-5, DASCON-1, Metrabyte Corporation, Taunton, MA), and solid-state controllers (BRS/LVE, Inc.) were used to monitor subject responses and control the onset and duration of the VDDs, and auditory feedback. A compiled algorithm written in Quick-BASIC (Microsoft Corp., Redmond, WA) provided control over the function of these peripheral devices.

Corrective spectacles. Each participant received a free pair of corrective PALs at no cost (Varilux Infinity, Varilux Corporation, Foster City, CA). Each subject also possessed a pair of bifocal lenses with standard 22-mm segments (ST-25, American Optical). Bifocal lenses offered near correction for reading distance (≈ 40 cm). Add powers ranged from 1 to 2.25 ($M = 1.917$, $SEM = .11$). Subjects were allowed between 3 days and 4 weeks to adapt to their PAL lenses.

PROCEDURES

Subjects were tested individually. They participated in three practice and two experimental sessions over 5 successive days (one session per day). Subjects sat in an A/4 ejection seat located behind an F/15 cockpit windscreen assembly in a completely darkened room for the first 5 min of each experimental session. Following this dark-adaptation period, the center area of each video display device was illuminated by the word 'GO.' Subjects pressed the display-advance button, held in their nondominant hand, to reveal a visual array on one of the three VDDs in front of them. Their task was to identify the location of a single target rectangle as quickly as possible (without sacrificing accuracy) by pressing one of four response keys with their dominant hand. Each response key corresponded to a different quadrant of the visual display. The keys were placed in a 3.5-cm wide by 2.5-cm array on an aviator knee-board.

For each trial, the display remained on until the subject responded, or for 2.8 s, whichever occurred first. On days 1 and 2, the display remained on for a longer period of time (30 and 3.2 s, respectively). Longer display times were needed on these days to facilitate practice. After the subject responded, the word 'GO' reappeared in the center of each VDD indicating that the response had been recorded and the next trial was ready to begin. Displays appeared in quasi-random order such that on the following trial the visual array was displayed on one of the VDDs not viewed on the previous trial. Correct target-location responses were llowed immediately by a high-pitched tone, whereas incorrect responses were followed by a low-pitched e.

Subjects viewed two display sets (120 trials each) each day, one while wearing bifocal lenses, and the other while wearing PALs. The order in which the corrective lenses were worn (bifocal first or PAL first) was counter-balanced. Subjects participated for 5 successive days. Each experimental session was 15-20 min long.

Recording of subject response time to locate a target was time-locked to visual display onset. Subjects were shown their performance after each session. Furthermore, on the following day, each subject was shown how his previous day's performance compared to that of the other 11 subjects.

The independent variables in this study were, a) type of presbyopic correction (2 levels: bifocal and PAL), b) target eccentricity (5 levels: 1.0, 2.4, 3.8, 4.3, and 5.3°) and, c) accommodation distance (40, 83, and 280 cm). The dependent variables were response accuracy, and response latency.

RESULTS

We used a completely within-subjects repeated-measures analysis of variance (ANOVA) design to evaluate the effects of the experimental treatments on the accuracy and latency of target-location responses. Post-hoc pairwise comparisons among means were performed using Tukey's HSD test at the 0.05 probability level. Speed and accuracy-of-responding data from days 4 and 5 (nontraining days) were considered for analysis below. Only correct target-location responses were used in the analyses. The effect of presbyopic correction on target-location performance was examined in a two-by-three-by-five way repeated-measures ANOVA (correction, bifocal and PAL; accommodation distance, 40, 83, and 280 cm; target eccentricity, 1.0, 2.4, 3.8, 4.3, and 5.3°). Type of presbyopic correction and accommodation distance interacted to significantly affect latency of target-location responses [$F(2, 22) = 5.88$, $p < .01$]. Post-hoc pairwise comparisons between presbyopic correction (bifocal vs PAL) at each accommodation distance revealed that the latency of target-location responses was significantly faster when wearing the PAL correction for presbyopia (see Fig 4). Specifically, mean response latency when wearing PALs was significantly lower ($M = 1992$, $SEM = 56$)

compared to bifocals (M = 2103, SEM = 57). No other significant effects involving type of presbyopic correction were observed for latency or accuracy of target-detection responses.

Subjective responses from a post-seven-month questionnaire were revealing. Seven of the 12 participants (58%) indicated that they used their PAL correction exclusively when flying the T-39 Sabre Liner. Three subjects (25%) used their PAL correction intermittently (primarily at night) when flying and two subjects preferred not to use the PALs when flying.

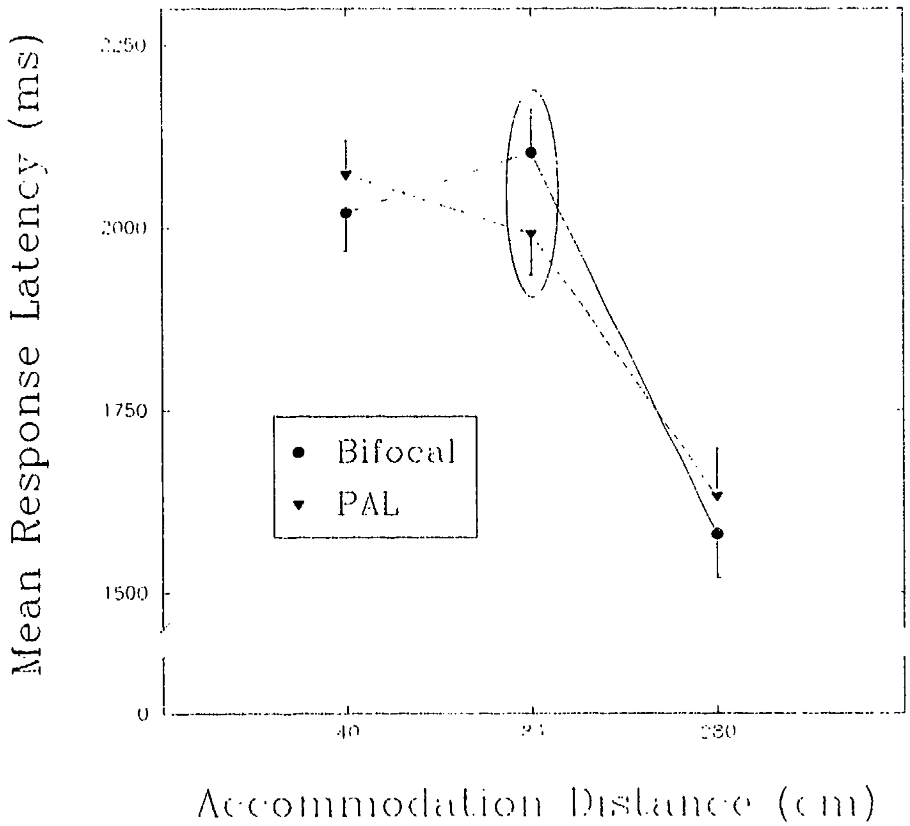

Figure 4. Latency (mean response time) of target location responses as a function of presbyopic correction and accommodation distance.

CONCLUSIONS

In summary, high-contrast targets viewed under dawn/dust lighting conditions (≈ 3.0 cd/m²) were located with equal *accuracy* when wearing bifocal or PAL corrections. However, *latency* of responding to high-contrast targets under the same viewing conditions was differentially affected by the type of presbyopic correction used. Specifically, compared to a standard bifocal (ST-25), a PAL correction (Varilux Infinity) significantly decreased the time needed to locate high-contrast targets at an intermediate viewing distance (83

cm). These results *suggest* that a) subjects were able to adapt to PALs quickly, and b) relative to bifocals, speed of responding to static targets at intermediate viewing distances may be improved by wearing PALs.

These results do not, a) address all the mechanisms by which PALs may reduce (improve) the latency of target-detection responses at an intermediate viewing distance, or b) allow generalizing to the presbyopic aviator population at large. Previous research (22) suggests that a combination of eye-head coordination factors, including saccadic gain control, could be involved in the adaptation process. In addition, the clear field of view required for target detection in this study (± 5°) may not have forced subjects to use, or compensate for, the nonspherical portion of the PAL lens. Use of a wider cockpit display would be helpful for addressing this issue. Furthermore, the extent and shape of the area of a PAL lens compromised by nonspherical surfaces varies as a function of both the manufacturing process and add power. Consequently, these results can be generalized only to individuals wearing the Varilux Infinity PAL with no greater than 2.25 D add.

Finally, wearing any type of corrective spectacle poses a unique set of problems for aviators that must not be ignored when considering adaptability to the aviation environment. These include but are not limited to obstructed field of view, fogging, nasal and ear discomfort, reflections (day or night), excessive frame movement due to G-forces and vibration (19), and increased mean target-detection times (25).

RECOMMENDATIONS

We recommend continued investigations of the use of PALs as an alternative form of presbyopic correction for naval aviators. Future studies should include human performance data, such as speed and accuracy of target detection/identification, as additional objective measures to assess the suitability of progressive addition lenses to an aviation environment. Of course, human performance data should not be viewed in isolation of other salient issues such as modulation transfer, psychophysical observations, human factors (including spectacle-induced head movement), and patient adaptability to inherent PAL astigmatism. Because manufacturing technique influences the nature of nonspherical aberrations in PAL lenses, future research should compare lenses from several manufacturers.

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13. ABSTRACT *(Maximum 200 words)*

The objective of this project was to determine if the type of presbyopic correction worn by aviators, conventional bifocal versus progressive addition lenses (PALs), differentially affects aviator visual search performance. Experienced aviators with tactical fighter aircraft experience searched for high-contrast targets under dawn/dust lighting conditions ($\approx$ 3.0 cd/m^2) while wearing either a standard bifocal (ST-25) or PAL spectacle correction. Latency of locating high-contrast targets under these viewing conditions was affected differentially by the type of presbyopic correction used. Specifically, compared to a standard bifocal (ST-25), a PAL correction (Varilux Infinity) significantly lowered the time needed to locate static targets at an cockpit-instrument distance (83 cm). Accuracy of target-location responses was not affected by the type of correction used. In addition, 7 months post experiment, 7 of the 12 participants (58%) indicated that they used their PAL correction exclusively when flying the T-39 Sabre Liner. Three subjects (25%) used their PAL correction intermittently (primarily at night) when flying, and two subjects preferred not to use the PALs. These results suggest that a) relative to bifocals, speed of responding to static targets at cockpit-instrument distances may be improved by wearing PALs', and b) subjects were able to adapt to PAL lenses quickly in a laboratory setting, using them later in a functional aviation environment.

14. SUBJECT TERMS

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