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Preliminary Evaluation of Visual and Flight Performance of Three Current Multifocal Contact Lens Designs for Presbyopic U.S. Army Aviators

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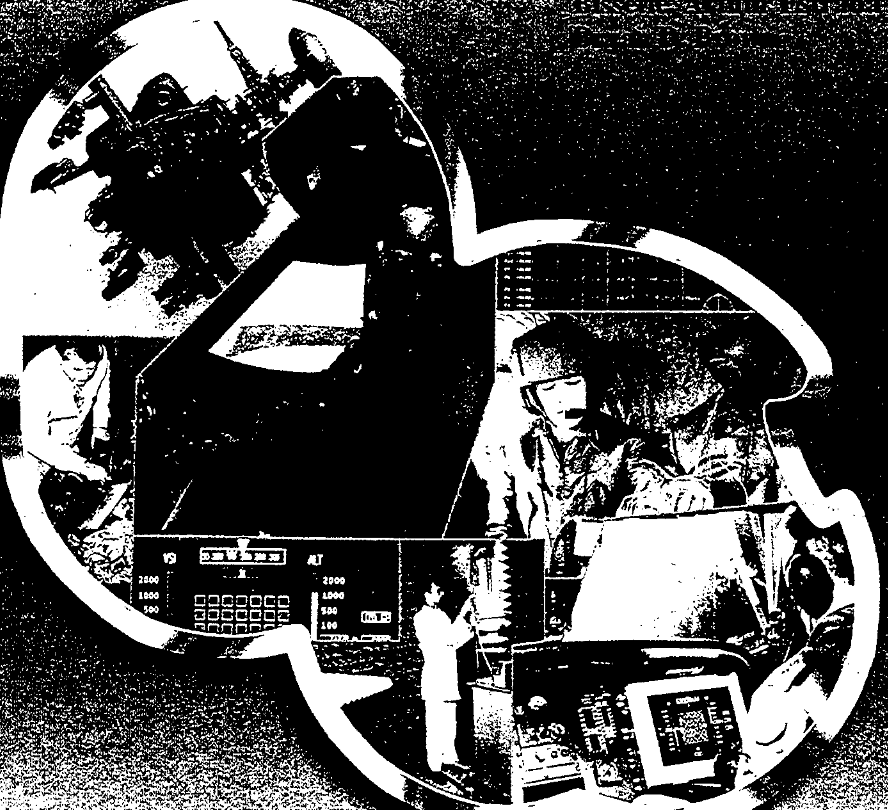

Aircrew Health and Performance Division

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13. ABSTRACT *(Maximum 200 words)*
U.S. Army aviators have been authorized to wear contact lenses for aviation duties with special waiver since 1991. The authorized contact lens modality is the single-vision soft contact lens that corrects for 20/20 distance and near. As aviators become presbyopic, they often have to return to bifocal spectacle wear or readers over their distance contact lenses in order to complete their aviation duties. Spectacles introduce interface problems with head-mounted displays and night vision goggles. This pilot study evaluated the potential utility of multifocal contact lenses to provide adequate visual and flight performance for presbyopic aviators. Bifocal spectacles or readers provide better levels of visual performance than any of the three multifocal contact lenses evaluated. Flight performance in a UH-60 simulator under daytime conditions was not decremented with the multifocal contact lenses evaluated in this study; however, this study did not evaluate night flight, interface with head-mounted displays or night vision goggle flight performance. Studies specific to the Apache flight environment are being considered since visual performance remained within norms and Apache pilots are faced with greater interface problems with bifocal spectacles and head-mounted displays and protection mask configurations than pilots in other aviation platforms. Many Apache pilots have been permanently grounded or converted to other platforms due to the onset of presbyopia and spectacle compatibility issues in the cockpit. Multifocal contact lenses, when fit to specific parameters, may be an option under special circumstances where spectacles would lead to reduced performance.

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Introduction

Aviators have always had to meet stringent physical standards to gain and maintain flying status. Some standards are more flexible than others; refractive error is an example of the type of standard that allows some departure from absolute emmetropia. Up to a substantial 25% of the aviation population develops ametropia requiring the use of spectacles or other refractive correction after the completion of flight training (Lattimore and Schrimsher,1993). The use of spectacles is problematic with certain electro-optical sighting systems, particularly in the Apache. Fortunately, disposable extended wear soft contact lenses have proven to be an effective solution for dealing with the spectacle compatibility problems for a large proportion of aviators requiring refractive error corrections (Lattimore,1992).

Older, more experienced aviators are naturally losing their ability to focus on near objects, a process called presbyopia. Eventually, presbyopic changes force all aviators, even those who have never worn glasses or contacts, to use a correction in order to see their flight controls and read approach plates and maps. Since single vision contact lenses only correct distance vision, the aging aviator must adapt to these changes by reverting to bifocal spectacle wear or wearing readers over their contact lenses. Bifocal spectacles or readers may lead to an inability to continue flying certain aircraft platforms such as the Apache that depend on the use of head-mounted display (HMD) systems. Therefore, it is important to take measures to prevent the loss of these most experienced and qualified aviators.

One means of correcting presbyopia using contact lenses is monovision. This method fits the patient with a distance contact lens on one eye and a near contact lens on another. While this is a very popular modality, it has limited appeal for military application due to the potential reduction in binocular vision. A 1996 civil aviation accident was attributed to the pilot's use of monovision contact lenses (Nakagawara and Veronneau,2000). Multifocal contact lenses are another modality and offer a potential improvement over the compromises of monovision. This type of lens provides both distance and near correction within each lens, often referred to as "simultaneous vision." The results of a previous study by Morse showed that multifocal contact lenses can be compatible with the Army Aviation environment. The reduced quality of vision with multifocal contact lenses and lack of a single lens type or modality best suited for all aviators across the board raised concerns (Morse and Reese,1997).

Recent advances in multifocal contact lens designs have produced lenses potentially better suited to the visually-demanding environment of the presbyopic Army aviator. These advances include more refined aspheric designs and the development of lenses utilizing concentric alternating near and far focal zones. In this study, a preliminary evaluation of commercially available disposable multifocal soft contact lenses using the standard binocular fit was completed. The primary objectives of the study were to (1) determine whether new generation multifocal contact lens designs show potential to provide adequate vision compatible with the basic occupational tasks and environmental conditions unique to Army aviators (2) determine whether there is a general trend towards acceptance of a binocular multifocal contact lens fit (3) determine whether any of the new generation contact lenses are strongly preferred or strongly rejected by the small pilot sample and (4) determine if any of the tested new generation multifocal contact lenses or lens modalities shows a clear advantage over the others for follow-on studies. Studies of the new generation of multifocal contact lenses could ultimately lead to recommended fitting procedures and clinical tests that might be relevant to visual performance in the cockpit.

This study was supported by an Independent Laboratory Innovative Research grant (Medical Research and Materiel Command, Army Medical Department).

Methods

Subjects

Twenty-one volunteer presbyopic aviators already wearing bifocal spectacles or reading glasses in the performance of their flight duties and stationed or living in the Fort Rucker, Alabama area were identified through local advertisement. Institutional Review Board approval was obtained for the study. The risks of participation in the study were explained to potential subjects and provided in a written consent form. All participants provided informed consent for the study. Although the flight testing was completed in a UH-60 Black Hawk simulator, pilots rated in other aircraft were included since the skills required for completion of the flight tasks in this study were common to all platforms.

Subjects had to meet Flight Duty Medical Examination (FDME) standards (correctable to 20/20 distance and near) and could not have greater than or equal to 0.75 diopters of astigmatism in their dominant eye, since multifocal contact lenses do not correct for astigmatism. Medical conditions that excluded subjects from participation included: (1) chronic or acute inflammation of the anterior segment of the eye; (2) disease processes affecting the sclera, conjunctiva, or cornea of the eye; or (3) any systemic disease which affects the anterior segment of the eye.

The study was to continue until 20 subjects were able to wear contact lenses and had been entered into the study; however, only 18 subjects were able to complete the protocol. Two subjects completed some of the testing, but were unable to complete the study due to scheduling conflicts, and one subject failed to return after initial refraction and baseline testing. None of the subject withdrawals were as a result of contact lens problems or inability to wear contact lenses.

Materials

All multifocal contact lenses used in this study were FDA approved disposable multifocal soft contact lenses. The Acuvue® Bifocal lens uses an alternating five-zone concentric distance and near design to provide simultaneous distance and near focus for the wearer. Both the Ciba Focus® Progressive and the Bausch & Lomb Soflens® Multi-focal lenses use an aspheric design which provides increased near power towards the center of the lens. The contact lenses were fit according to the recommended fitting guide provided by the manufacturer of each contact lens design. A licensed Optometrist completed all contact lens fittings and a certified ophthalmic technician assisted in subject training. The contact lenses used in this study are listed in Table 1.

Table 1.
Contact lens parameters.

Lens Design	Lens Parameters	
Acuvue® Multifocal Concentric design; center distance with 5 alternating zones (disposable)	Material:	etafilcon A
	Water Content:	58%
	Options:	Light blue tint 1-2-3 inversion indicator
	Diameter:	14.2
	Base Curve:	8.5
	Center Thickness (mm):	0.075 @ -3.00 0.165 @+3.00
Bausch & Lomb Soflens® Multi-focal Aspheric design; center near (disposable) Natra-Sight™ Optics	Material:	polymacon
	Water Content:	38%
	Options	Light blue handling tint
	Diameter:	14.5
	Base Curve:	8.5, 8.8
	Center Thickness (mm):	0.10 @ -3.00
CIBA Focus® Progressives Aspheric design (disposable)	Material:	vifilcon A
	Water Content:	55%
	Options:	Visitint®
	Diameter:	14.0
	Base Curve:	8.6, 8.9
	Center Thickness (mm):	0.10 @ -3.00 0.16 @ +3.00

Procedures

Each subject received a complete eye examination to determine the appropriate spectacle prescription and ocular parameters specific to contact lens fitting, including refraction, slit lamp examination, and corneal curvature measurements using an Orbscan II corneal topographer (Bausch & Lomb, Rochester, NY). All procedures were noninvasive standard clinical tests. If the measured prescription varied by more than 0.25 diopters distance or near from the subject's habitual prescription, bifocal spectacles were fabricated into standard U.S. Army flight frames using the spectacle prescriptions determined at this first examination. Availability of trial contact lenses in the parameters needed for the subject was verified and specific trial lenses were ordered.

Subjects received a preliminary fit with one of the multifocal contact lens types using a randomization protocol. Subjects who had not worn contact lenses prior to this study received training in the insertion, removal and care of contact lenses. Subjects were not allowed to continue contact lens wear if they did not adequately demonstrate to the optometrist that they had the capability to handle the contact lenses. Subjects who had worn contact lenses before were given an update on the procedures to handle contact lenses and their skills were evaluated by the optometrist prior to the release of their first pair of contact lenses. In keeping with standard optometric practice, all new contact lens fits were monitored for at least a half an hour prior to release of the subject. Subjects were provided with either ReNu MultiPlus® Multi-Purpose Solution or Complete® brand Multi-Purpose Solution for care of the contact lenses.

After wearing the contact lenses for 7 days, subjects returned for an adjustment examination. An adjustment of lens powers was made as needed to achieve optimal vision. Subjects were given up to two adjustment fittings, if needed, to achieve optimal vision. Inability to achieve acceptable near and far vision, at least 20/20 acuity, after two adjustments was considered a fitting failure for that lens modality. If no adjustment was needed, the subject completed the vision and flight-testing. If an adjustment was needed, the subject wore the lenses for an additional 7 days before returning for testing. Since multifocal contact lens wear is not approved for flight, subjects were not allowed to wear the contact lenses during the performance of flight duties outside of this study's control. The subject was advised to remove the contact lenses at least 1 hour prior to operating any aircraft other than during the simulator flight evaluations conducted as part of this study.

Subjects completed testing with bifocal spectacles at the beginning of the study. Testing consisted of vision evaluations (Table 2), simulator flight (Appendix A), and a survey (Appendix B). Then testing was completed after each contact lens fitting cycle for all three contact lens types. The order in which multifocal lenses were fit was randomized for each subject. After contact lens testing, the subjects again completed all testing with their bifocal spectacles. The two bifocal spectacle sessions were used to establish baseline performance levels.

Vision testing

High contrast visual acuity was evaluated with an ETDRS visual acuity chart (chart developed in the Early Treatment of Diabetic Retinopathy Study) tested at 4 meters. Unlike standard clinical projected charts, the ETDRS uses a logarithmic progression of letter size (0.1 per row), a constant number of letters per row, and letters of equal legibility, making task difficulty constant, regardless of the level of acuity tested (Bailey and Lovie,1976); (Bailey et al., 1991). Testing was conducted binocularly at standard (200 cd/m^2) luminance levels. The chart was retro-illuminated by a calibrated fluorescent light box, and acuities were scored *by letter* (number of letters read correctly) in log of the minimum angle of resolution units (log MAR; 0.02 log units per letter). The chart version (i.e., letter sequence) was alternated between trials to discourage learning effects. Near high contrast visual acuity was measured using the SKILL card (developed at Smith Kettlewell Institute, California) at a 40 centimeter testing distance (Haegerstrom-Portnoy et al., 1997). Scoring of this card is the same as that used for the distance chart (logMAR units). At baseline, uncorrected visual acuity (UCVA) was measured. For all subsequent evaluations, visual acuity was measured using either bifocal spectacles, reading spectacles or the multifocal contact lens correction (HCVA).

Low contrast visual acuity was evaluated with the Precision Vision (LaSalle, Illinois) 5% low contrast log MAR visual acuity chart. Testing was conducted binocularly at 4 meters at normal (200 cd/m^2) and low luminance levels (2 cd/m^2) with spectacle or contact lens correction. The low luminance condition was achieved by placing a 2.0 neutral density filter in the illumination path of the light box. All acuities were scored by letter in log MAR units (0.02 log units per letter). Near low contrast visual acuity was measured using the reverse side of the SKILL card at 40 centimeters. The card has a contrast level of 5% (dark background with grey letters). Scoring of this card was the same as that used for the distance chart (logMAR units).

Glare testing was conducted with the Precision Vision Glare Test with the 5% low contrast ETDRS chart. The test utilizes two rheostat-controlled incandescent spotlights separated by 9.4 degrees, simulating oncoming headlights at 35-40 feet. The glare sources straddle the low contrast chart presented in the center of the illumination box. Testing was completed binocularly with spectacle or contact lens correction. Scoring on the glare test was recorded in terms of 5% LCVA logMAR under glare conditions.

Spatial contrast sensitivity was assessed with the Vision Works Contrast Sensitivity System, which displays periodic grating patterns of varying spatial and temporal frequency. Thresholds were determined for 1, 2, 4, 8 and 16 cycle per degree (c/deg) spatial frequencies. Testing was conducted binocularly at normal (approximately 100 cd/m^2) and mesopic luminance levels (approximately 1 cd/m^2) with spectacle or contact lens correction. A composite score based on the area under the contrast sensitivity function (AUCSF) was determined using the combined sensitivity scores across all the spatial frequencies tested.

Stereopsis was tested using the Armed Forces Vision Tester (AFVT) to determine distance stereopsis and the Randot Stereo Circles test to determine near stereopsis. Testing was completed with spectacle or contact lens correction in place. Both stereo measures were reported in seconds of arc.

Pupil size was assessed with an infrared digital pupillometer (Neuroptics®) while viewing the letter charts under photopic (200 cd/ m^2) chart luminance levels, and under mesopic (1-2 cd/m^2) levels. Pupil diameter was recorded in millimeters.

Table 2.
Vision testing.

Visual performance measures*	Test and norms
High contrast visual acuity (HCVA)	ETDRS logMAR chart at 4 meters: 0.00 logMAR (20/20 Snellen) SKILL card at 40 centimeters: 0.00 logMAR (20/20 Snellen)
Low contrast visual acuity (LCVA)	ETDRS logMAR 5% low contrast chart at 4 meters: 0.30 logMAR (20/40 Snellen) ETDRS logMAR 5% low contrast chart at 4 meters (with 2.0 ND filter): 0.48 logMAR (20/60 Snellen) SKILL card (14% low contrast, luminance side) at 40 cm: 0.48 logMAR (20/60 Snellen)
Glare disability (GD)	ETDRS 5% logMAR low contrast chart with glare source at 4 meters: 0.30 logMAR (20/40 Snellen)
Contrast sensitivity (CS)	Vision Works computerized CSF: 200 AUCSF
Mesopic contrast sensitivity (MCS)	Vision Works computerized CSF (low luminance): 115 AUCSF
Stereopsis	Armed Forces Vision Tester (simulated distance): 40 seconds of arc Randot Stereo Test (near): 40 seconds of arc
Ocular parameters	**Test**
Pupil Size under photopic and mesopic conditions	Neuroptics® Pupillometer with standard and low ambient light levels

* All visual performance tests were completed binocularly.

Flight testing

Simulator testing protocols were used to assess flight performance for each contact lens condition and bifocal spectacles using a 45-minute flight profile under day conditions. The flight profile and task listings are provided in Appendix B. Performance of the subject on each maneuver was rated by the research aviator in accordance with standards established in TC 1-212 Aircrew Training Manual, Utility Helicopter, UH-60/EH-60. The research aviator observing the flight entered a score from 1 to 5 for each maneuver during the flight. A score of 3 denotes performance in accordance with standards; scores of 4 or 5 indicate more precise performance and scores of 2 or 1 indicate less precise performance. The following sections detail the specific tasks in the protocol and what aspects of vision and aircraft control they represented.

Right hovering turn (task 1)

This task required the subject pilot to coordinate pedal input and cyclic control to pivot the aircraft through 360 degrees around a given point above the ground. Visually, the pilot had to constantly check inside and outside the aircraft to maintain power (by checking the torque), check time, and maintain height and position above the ground (visualize the radar altimeter and the horizontal situation indicator (HSI) and monitor rate of movement over the ground). The hover turn condition was the in-ground effect (IGE) at 10 feet. Standards for this task were to complete the turn in the stated time while maintaining height and position ρ 3 feet for the IGE hover turn.

Visual meteorological conditions (VMC) takeoff (tasks 2 & 6)

Takeoff from the ground required balancing input to the cyclic, collective and pedals of the aircraft maintained heading and the proper amount of acceleration. During the takeoff sequence, the pilot had to maintain 10% above hover power for acceleration to the required airspeed of 80 knots (ρ 10 knots), which required vigilance of torque, heading, altimeter, and airspeed indicators, while maintaining the desired rate of climb of 500 feet per minute (ρ 100 fpm) by monitoring the instantaneous vertical speed indicator (IVSI) and sustained track across the ground while minimizing drift. Up to 50 feet above ground level (AGL), the pilot had to maintain aircraft heading (ρ 10 degrees), and above 50 feet AGL, the aircraft was placed in trim while maintaining track to minimize drift. Visually, the pilot had to alternate between checking inside to maintain speed, rate of climb, power (monitor torque), and heading and checking outside to maintain ground track and airspace surveillance.

Straight and level (tasks 3 & 7)

Prior to this task, the pilot made another 90-degree turn to the downwind leg. To hold the aircraft to straight and level flight at 1000 feet MSL and 100 knots, the pilot had to monitor airspeed, altitude, heading, and trim while checking outside the aircraft for ground track and airspace surveillance. During one of the two straight and level maneuvers, the simulator operator presented the subject with an emergency procedure requiring the pilot to read the emergency procedure and to visualize a control panel button and take appropriate action.

Decelerating descent (tasks 4 & 8)

The pilot had to monitor the IVSI to establish the 500 fpm descent rate, and then started a 90-degree turn reducing airspeed to 80 knots to enter the base leg at 700 feet MSL. Crosschecks between aircraft flight instruments and the horizon and ground position were important for this maneuver.

Final approach (tasks 5 & 9)

The pilot determined the approach angle that allowed safe obstacle clearance while descending to the intended point of landing, in this case the departure or far end of the runway. Depth perception was very important for this task as the pilot had to maintain 80 knots until apparent rate of closure started to increase, approached angle, minimized drift and stayed on track. The pilot maintained ground track alignment with the landing direction by maintaining the aircraft in trim above 50 feet AGL and slipped (aligned) the aircraft to maintain the landing direction and straddled the center line of the runway below 50 feet AGL.

Formation flight (task 10)

The pilot's task was to follow a lead ship from the airfield for a 10-minute timeframe. This task involved judgment of distance while maintaining vigilance of flight controls and instrumentation. In a staggered left trail formation, the pilot had to maintain at least 3 to 5 rotor disk diameters space from the lead aircraft, 30 to 45 degrees astern and 1 to 10 feet vertical step-up.

Admin vectors to ILS (task 11)

The safety pilot took the controls during this segment of flight. The subject's tasks included determining frequencies using the approach plate for Cairns Army Airfield, setting frequencies for both the VOR/ILS (very high frequency omnidirectional range/ instrument landing system) radio and setting the automatic direction finder (ADF). The subject had to select the inbound course for ILS into the HSI and ensured that proper selections were made on the mode select panel for the VOR/ILS and ADF/VOR.

ILS approach (task 12)

This task had the highest near visual demand of all the maneuvers due to the requirement to constantly cross check a number of instruments. Instrument crosscheck required observing and interpreting two or more instruments to determine altitude and aircraft performance. In instrument flight, instruments had to be properly crosschecked and correctly interpreted to detect any malfunction and to control the aircraft in the desired flight path. Instruments provided (1) a reference of aircraft altitude, (2) a reference for use of power and (3) an indication of whether the combination of altitude and power was producing the desired performance. The course deviation bar, roll command bar and the pitch command bar in the vertical speed indicator (VSI) had to be monitored. Altitude, airspeed, torque, and heading also were monitored.

Survey

A survey to determine how well subjects felt they were able to complete flight tasks was given to each subject following the simulator phase (Appendix C). Survey ratings for flight in *bifocal spectacles* and *contact lenses* were set up on a scale from 1 to 7, defined as (1) very difficult, (2) moderately difficult, (3) slightly difficult, (4) neither difficult nor easy, (5) slightly easy, (6) moderately easy, and (7) very easy. The items surveyed included: reading checklist, setting frequency, target/object detection, formation flight and overall performance. The subjects then rated *current lenses (contact lenses) to spectacles* on these same items on the seven point scale in terms of (1) much poorer, (2) moderately poorer, (3) slightly poorer, (4) same as glasses, (5) slightly better, (6) moderately better, and (7) much better. The *contact lens* survey included questions about the general vision, comfort and handling of the contact lenses during daily activities.

Data analysis

The purpose of this study was to determine general trends for or against the use of new generation disposable multifocal contact lenses in the aviation environment. A sample size of 15 subjects was sufficient to provide 90% power at $\Delta = 0.05$ for the proposed analysis in this protocol (nQuery Advisor 4.0). This was based on the minimum analysis of 2 levels (bifocal spectacles versus best contact lens modality) and 0.01 logMAR variance of means for vision tests.

Visual performance, flight performance, as well as subjective survey assessment of the contact lenses by the pilots were analyzed relative to these measures under bifocal spectacle conditions (control). The visual performance results with each contact lens modality were compared to the bifocal spectacle condition to determine statistical differences in visual performance. The types of contact lenses were compared in general to determine whether there was any strong preference or incompatibility problem with a particular lens type or brand.

Results

Subjects

The average subject was 52 years of age (range 44 to 60 years). All subjects enrolled were male. No female subjects applied to the study. The mean experience in flying hours of the subjects was 6624 (range 2000 to 12,000 hours). There were three OH-58 Kiowa pilots, three AH-64 Apache pilots, four UH-60 Black Hawk pilots, three UH-1 Huey pilots, three TH-67 Creek pilots, one CH-47 Chinook pilot and one C-12 pilot enrolled. Seven of the pilots were dual-rated in other aircraft. The mean refractive error across both eyes in terms of spherical equivalent was +0.10 diopters (range +1.88 hyperopia [far-sightedness] to –1.75 myopia [near-sightedness]), and a mean level of manifest presbyopia (add power) of +1.82 diopters (range +1.00 to +2.50 ADD). Mean high-contrast *uncorrected distance* visual acuity measured binocularly was 0.02 logMAR (20/21 Snellen equivalent); range –0.24 to 0.56 logMAR (20/12 to 20/73 Snellen). Average pupil size for these subjects was 2.5 millimeters (range 1.7 to 4.0) in high luminance conditions and 6.1 millimeters (range 4.1 to 7.8) in low luminance. Table 3 summarizes the subject demographics and baseline data; Appendix C provides specifics for each subject, including lens parameters for all three contact lens fits.

Table 3.
Demographics and baseline.

Demographics and Baseline		
	Mean ± SD	**Range**
Age	52 ± 5	44 to 60
Flight Hours	6624 ± 3084	2000 to 12000
Vision Baseline		
Spherical Equivalent (D)	0.10 ± 1.0	-1.88 to +1.75
Add Power (D)	1.82 ± 0.48	+1.00 to +2.50
UCVA (logMAR)	0.02 ± 0.27	-0.24 to 0.56
Pupil Size (mm) - High(100 cd/m^2)	2.5 ± 0.54	1.7 to 4.0
Pupil Size(mm) – Low (1-2 cd/m^2)	6.1 ± 0.95	4.1 to 7.8

Visual performance

Visual performance included assessment of high and low contrast, low luminance and depth perception at distance, and near and low contrast vision in the presence of glare for distance only. In most cases, the difference between bifocal spectacle and multifocal contact lens visual performance was within norms (less than one standard deviation difference from established norms); however, for low contrast visual performance, and especially near low contrast, the difference was greater. All subjects were able to see 20/20 at distance with at least one set of contact lenses. Five subjects were unable to attain 20/20 or better at near with any of the contact lens options. Based on current Aeromedical policy standards for contact lenses (which cover single vision distance, not bifocal or multifocal lenses), 12 of the 18 subjects were successfully fit with at least one of the contact lens types. Specifically, their high contrast visual acuity was 20/20 or better at distance **and** near. This subgroup of 12 is treated separately at the end of each section as "*Best Fit*." In the "*Best Fit*" group, four subjects were best fit with the *Acuvue bifocal*, six subjects wore the *Bausch & Lomb multi-focal*, and two subjects wore the *Ciba progressive*.

High contrast visual acuity

Distance vision (high contrast)

Mean high-contrast binocular visual acuity with *bifocal spectacle* correction measured using the ETDRS backlit chart was –0.20 logMAR (sd=0.05; 20/13 Snellen). High-contrast visual acuity results for the contact lens corrections were –0.06 logMAR (sd=0.09; 20/17 Snellen) for the *Acuvue bifocal*, -0.08 logMAR (sd=0.10; 20/17 Snellen) for the *Bausch & Lomb multi-focal*, and –0.10 logMAR (sd=0.07; 20/16 Snellen) for the *Ciba progressive*. Paired t-test results show performance with contact lenses was significantly worse ($p<0.001$) than with bifocal spectacles; however, mean performance was 20/20 or better with all three contact lenses, the expected standard for distance acuity. For the *Best Fit* subgroup (n=12), acuity was –0.12 logMAR (sd=0.06; 20/15 Snellen), which was better than any one lens type, but still significantly worse ($p<0.001$) than with bifocal spectacles. The best distance acuity for contact lens correction under high-contrast conditions was with the *Best Fit* lens, though all contact lens modalities scored within a few letters of each other. See Figure 1.

Near vision (high contrast)

Mean near high-contrast binocular visual acuity with *bifocal spectacle* correction measured using the SKILL test (light side) was -0.10 logMAR (sd=0.10; 20/16 Snellen). High-contrast visual acuity results for the contact lens corrections were –0.02 logMAR (sd=0.10; 20/19 Snellen) for the *Acuvue bifocal*, 0.01 logMAR (sd=0.16; 20/20 Snellen) for the *Bausch & Lomb multi-focal* and 0.05 (sd=0.12; 20/22 Snellen) for the *Ciba progressive*. Paired t-test results show the performance with contact lenses was significantly worse ($p<0.001$) than with bifocal spectacles; mean performance was 20/20 or better with only the *Acuvue* contact lens, the expected standard for near acuity. For the *Best Fit* subgroup, near acuity was –0.09 logMAR (sd=0.07; 20/16 Snellen), which was better than any one lens type and not significantly different ($p=0.12$) from bifocal spectacles. The best near acuity under high contrast conditions in contact lenses was with the *Best Fit* lens; the three contact lens modalities scored within one line of each other. See Figure 1.

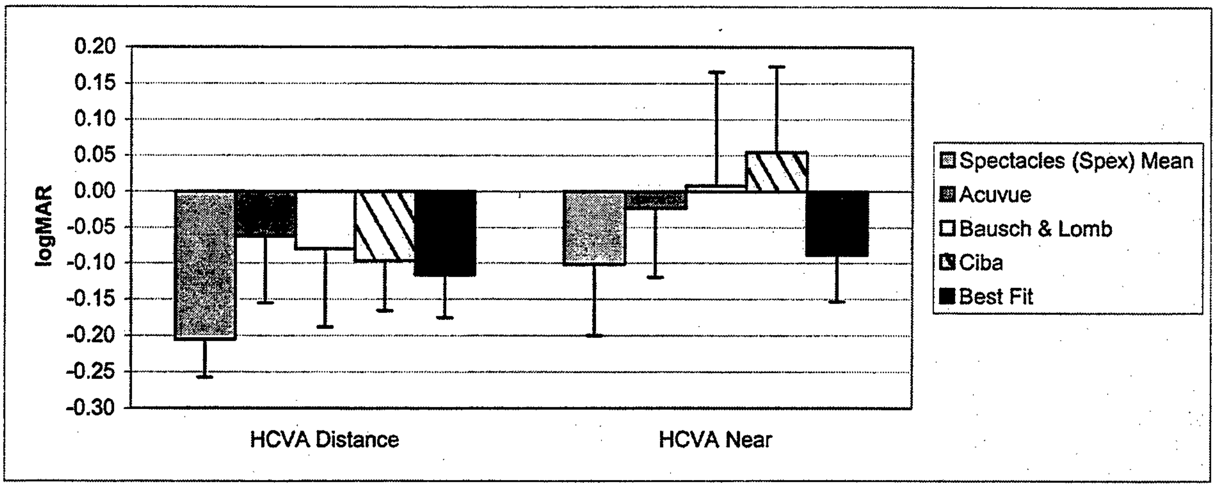

Figure 1. High contrast distance and near visual acuity.

Low-contrast visual acuity

Distance vision (low contrast)

Mean low-contrast binocular visual acuity with *bifocal spectacle* correction measured using the 5% ETDRS low contrast chart was 0.08 logMAR (sd=0.06; 20/24 Snellen). Low-contrast visual acuity results for the contact lens corrections were 0.28 logMAR (sd=0.11; 20/38 Snellen) for the *Acuvue bifocal,* 0.25 logMAR (sd=0.11; 20/36 Snellen) for the *Bausch & Lomb multi-focal* and 0.21 logMAR (sd=0.07; 20/32 Snellen) for the *Ciba progressive.* Paired t-test results showed the performance with contact lenses was significantly worse ($p<0.001$) than with bifocal spectacles; mean performance was 20/40 or better with all three lenses, the expected standard for 5% low contrast distance acuity. For the *Best Fit* subgroup, low contrast acuity was 0.23 logMAR (sd=0.08; 20/34 Snellen), which was essentially the same as the *Bausch & Lomb* lens and still significantly worse ($p<0.001$) than the bifocal spectacles. The best acuity under low contrast conditions in contact lenses was with the *Ciba progressive contact lens*, though all contact lens modalities scored within a few letters of each other. See Figure 2.

Distance vision (low contrast under glare conditions)

Mean binocular visual acuity in the presence of glare with *bifocal spectacle* correction was 0.08 logMAR (sd=0.07; 20/24 Snellen). Glare visual acuity results for the contact lens corrections were 0.27 logMAR (sd=0.10; 20/37 Snellen) for the *Acuvue bifocal,* 0.35 logMAR (sd=0.09; 20/45 Snellen) for the *Bausch & Lomb multi-focal* and 0.21 (sd=0.06; 20/32 Snellen) for the *Ciba progressive.* Paired t-test results showed the performance with contact lenses was significantly worse ($p<0.001$) than with bifocal spectacles; mean performance was 20/40 or better for the *Acuvue* and *Ciba* lenses, the expected standard for 5% low contrast distance acuity under glare conditions. For the *Best Fit* subgroup, glare acuity was 0.24 logMAR (sd=0.07; 20/34 Snellen), which is essentially the same as the *Ciba* lens and still significantly worse

($p<0.001$) than the bifocal spectacles. The best acuity under glare conditions was with the *Ciba progressive contact lens.* See Figure 2.

Distance vision (low-contrast, low luminance)

Mean low-contrast, low luminance binocular visual acuity with *bifocal spectacle* correction measured using a 5% low contrast ETDRS chart and a neutral density filter (ND 2) was 0.36 logMAR (sd=0.07; 20/46 Snellen). Low-contrast, low luminance visual acuity results for the contact lens corrections were 0.55 logMAR (sd=0.12; 20/71 Snellen) for the *Acuvue bifocal,* 0.50 logMAR (sd=0.09; 20/63 Snellen) for the *Bausch & Lomb multi-focal* and 0.45 (sd=0.06; 20/56 Snellen) for the *Ciba progressive.* Paired t-test results showed the performance with contact lenses was significantly worse ($p<0.001$) than with bifocal spectacles; mean performance was 20/60 or better with only the *Ciba* lens, the expected standard for 5% low contrast, low luminance distance acuity. For the *Best Fit* subgroup, low luminance acuity was 0.49 logMAR (sd=0.10; 20/61 Snellen), which is better than the *Acuvue* and *Bausch & Lomb* lens results, but still significantly worse ($p<0.001$) than the bifocal spectacles. The best acuity under low contrast, low luminance conditions was with the *Ciba progressive contact lens.* See Figure 2.

Near vision (low contrast)

Mean near low-contrast binocular visual acuity with *bifocal spectacle* correction measured using the low contrast side of the SKILL card was 0.32 logMAR (sd=0.13; 20/42 Snellen). Low-contrast visual acuity results for the contact lens corrections were 0.58 logMAR (sd=0.14; 20/76 Snellen) for the *Acuvue bifocal,* 0.59 logMAR (sd=0.14; 20/78 Snellen) for the *Bausch & Lomb multi-focal* and 0.74 logMAR (sd=0.13; 20/110 Snellen) for the *Ciba progressive.* Paired t-test results showed the performance with contact lenses was significantly worse ($p<0.0001$) than with bifocal spectacles; mean performance was worse than 20/60 with all three lenses, the expected standard for 5% low contrast near acuity. For the *Best Fit* subgroup, near low contrast acuity was 0.57 logMAR (sd=0.15; 20/75 Snellen), which was essentially the same as the *Acuvue* and *Bausch & Lomb* lens results and still significantly worse ($p<0.001$) than the bifocal spectacles. The best acuity in contact lenses under low contrast conditions was with the *Best Fit* lens. See Figure 2.

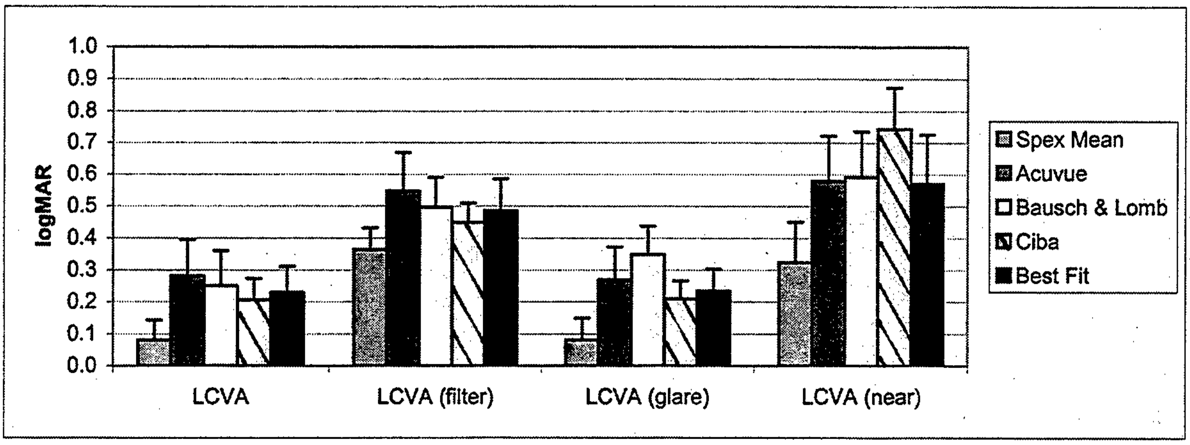

Figure 2. Low contrast distance visual acuity under standard luminance, low luminance, and glare conditions and low contrast near visual acuity.

Contrast sensitivity

The expected norm for the AUCSF in high luminance conditions is 200, and normal AUSCF in low luminance conditions is 115. The mean high luminance AUCSF for the *bifocal spectacle* condition was 199 (sd=18). The mean high luminance AUCSF results for the contact lens corrections were 187 (sd=40) for the *Acuvue bifocal,* 200 (sd=28) for the *Bausch & Lomb multi-focal,* and 187 (sd=25) for the *Ciba progressive.* There was not a statistically significant difference for high luminance contrast sensitivity performance with *bifocal spectacles* and any of the multifocal contact lenses ($p=0.51$). The mean low luminance AUCSF for the *bifocal spectacle* condition was 119 (sd=16). The mean low luminance AUCSF results for the contact lens corrections were 97 (sd=22) for the *Acuvue bifocal,* 109 (sd=23) for the *Bausch & Lomb multi-focal,* and 113 (sd=25) for the *Ciba progressive.* Paired t-test results showed the performance with the *Acuvue bifocal* contact lens was significantly worse ($p<0.001$) than with bifocal spectacles; however, there was not a statistically significant difference for low luminance contrast sensitivity performance for the *Bausch & Lomb* or *Ciba progressive* multifocal contact lenses ($p=0.11$). For the *Best Fit* subgroup, high luminance AUCSF was 198 (sd=21) and low luminance AUCSF was 112 (sd=23), which was not significantly different from the bifocal spectacles. The best CS under high luminance conditions was with the *Bausch & Lomb multi-focal* contact lens; and under low luminance conditions, the *Ciba progressive* contact lens. See Figure 3.

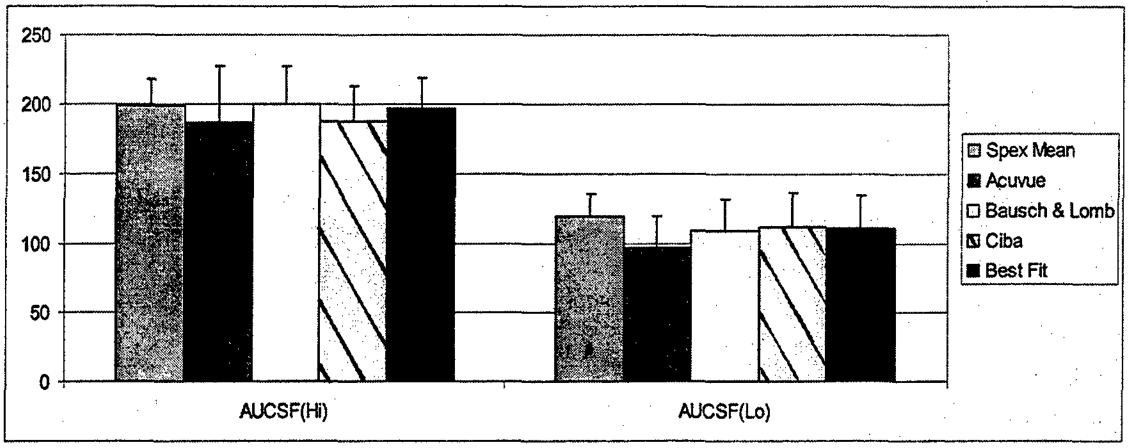

Figure 3. Contrast sensitivity under high and low luminance conditions in terms of AUCSF.

Stereopsis

Distance depth perception (AFVT)

Ninety-four percent of the subjects (17 out of 18) achieved 13 seconds of arc distance stereopsis with *bifocal spectacles*; only 1 subject had distance stereopsis worse than 40 seconds of arc (6%). Stereopsis measures for the *Acuvue bifocal* contact lens correction were 56% (10 subjects) with 13 seconds of arc and 78% (14 subjects) with 40 seconds of arc or better; for the *Bausch & Lomb, multi-focal* were 68% (12 subjects) with 13 seconds of arc and 89% (16 subjects) with 40 seconds of arc or better; and for the *Ciba progressive* were 83% (15 subjects) with 13 seconds of arc and 89% (16 subjects) with 40 seconds of arc or better. Comparison of distributions of distance stereopsis performance levels showed the performance with the *Acuvue bifocal* contact lens was significantly worse ($p<0.001$) than with bifocal spectacles; the distributions for the *Bausch & Lomb* and *Ciba* contact lenses did not differ significantly from the bifocal spectacles ($p=0.12$). For the *Best Fit* subgroup, stereopsis levels were 58% (7 subjects of 12) with 13 seconds of arc and 92% (11 subjects of 12) with 40 seconds of arc or better; not statistically significantly different from bifocal spectacles ($p=0.07$). The highest percentage of subjects with distance stereopsis within norms (40 seconds of arc) was with the *Best Fit* modality; both the *Bausch & Lomb* and *Ciba* lenses provided adequate stereopsis for 89% of subjects. See Figure 4.

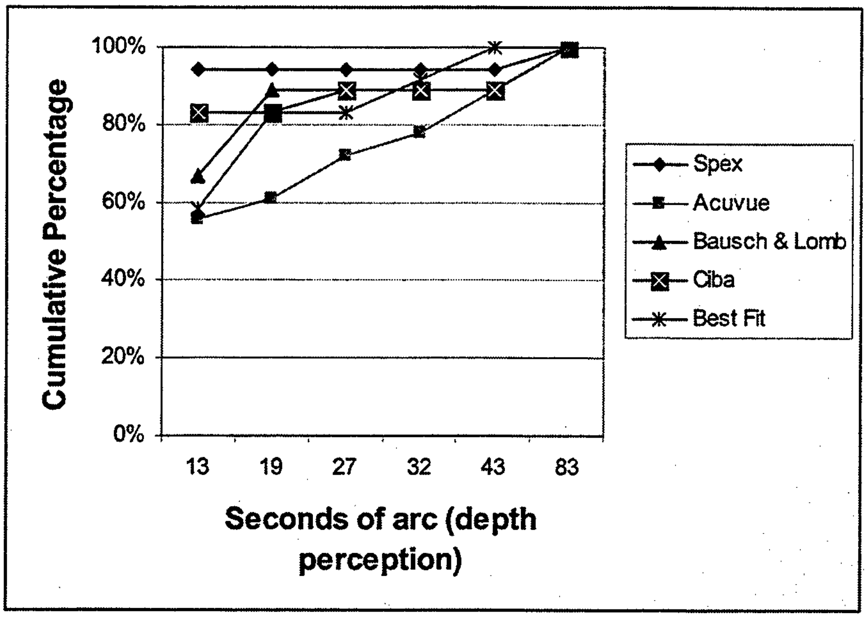

Figure 4. Cumulative percentage of stereopsis levels achieved on the AFVT (distance depth perception).

Near depth perception (Randot)

Eighty-nine percent of the subjects (16 out of 18) achieved 20 seconds of arc near stereopsis with *bifocal spectacles*; the remaining 2 subjects scored 40 seconds of arc or better (11%). Stereopsis measures for the *Acuvue bifocal* contact lens correction were 78% (14 subjects) with 20 seconds of arc and 100% with 40 seconds of arc or better; for the *Bausch & Lomb multi-focal* were 39% (7 subjects) with 20 seconds of arc and 100% with 40 seconds of arc or better; and for the *Ciba progressive* were 50% (9 subjects) with 20 seconds of arc and 89% (16 subjects) with 40 seconds of arc or better. Comparison of distributions of near stereopsis performance levels showed the performance was significantly worse than the bifocal spectacles for both the *Bausch & Lomb* contact lens ($p<0.001$) and the *Ciba* contact lens ($p=0.02$); the distribution for the *Acuvue* contact lens did not differ significantly from the bifocal spectacles ($p=0.06$). For the *Best Fit* subgroup, stereopsis levels were 58% (7 subjects of 12) with 20 seconds of arc and 100% with 40 seconds of arc or better; and was statistically significantly different from the bifocal spectacles ($p=0.04$). All contact lens modalities achieved stereopsis within norms (40 seconds of arc) for all subjects except the *Ciba progressive* lens. See Figure 5.

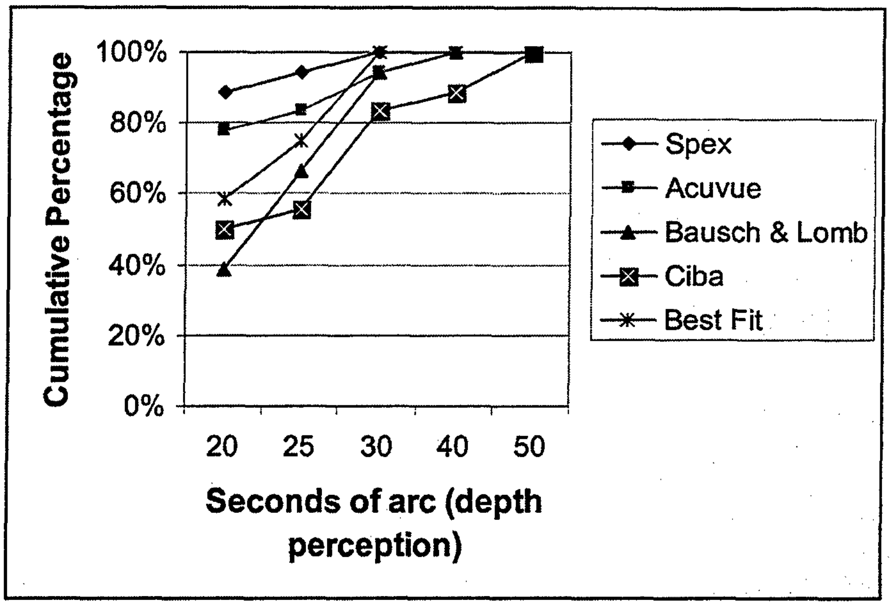

Figure 5. Cumulative percentage of stereopsis levels achieved on the Randot Stereo Test (near depth perception).

Flight performance

Each subject was scored by an instructor/research pilot in the UH-60 simulator in both bifocal spectacles and each of the three contact lenses. Scoring was set up for 12 separate tasks. The tasks were defined as (1) IGE Right Hovering Turn (360), (2) VMC Takeoff (500fpm) Upwind Leg, (3) Straight and Level Downwind Leg, (4) Turn/Decelerating/Descent Base Leg, (5) VMC Approach (500fpm) Final Leg, (6) VMC Takeoff (500fpm) Upwind Leg, (7) Straight and Level Downwind Leg, (8) Turn/Decelerating/Descent Base Leg, (9) VMC Approach (500fpm) Final Leg, (10) Formation Flight, (11) Admin Vectors to ILS/Emergency Procedure, and (12) ILS Runway 6. The heading, altitude and airspeed were defined for each task. Scoring was set on a scale from 1-5, with one being the lowest score and five being the highest.

In *bifocal spectacles*, the mean flight performance score was 3.07 (sd=0.59) over all 12 tasks. In the *Acuvue bifocal* contact lens, the mean flight performance score was 2.94 (sd=0.42), the *Bausch & Lomb multi-focal* contact lens score averaged 3.29 (sd=0.58), and the *Ciba progressive* contact lens score averaged 2.86 (sd=0.44) over the 12 tasks. Flight performance with any of the three contact lenses did not differ significantly from the performance with the bifocal spectacles (p=0.13). For the *Best Fit* subgroup, the mean flight performance was 3.10 (sd=0.43) and did not differ from the bifocal spectacles. See Figure 6.

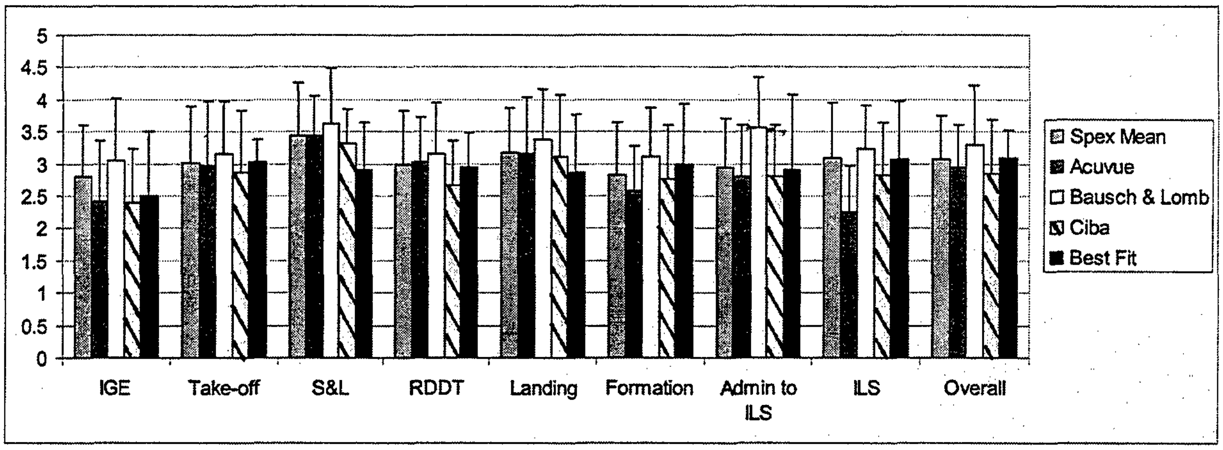

Figure 6. Mean individual flight performance scores and overall flight performance score for each correction condition.

Subjective assessment

Subjects assessed the performance of their bifocal spectacles and each of the three contact lens fits after their flight in the NUH-60 flight simulator. Performance was assessed for the individual tasks and then compared to performance with the bifocal the spectacles. The surveys for the bifocal spectacles and multifocal contact lenses are shown in Appendix B.

Overall rating

The mean overall rating for flight in the *bifocal spectacles* was 5.67 (sd=0.96). For the contact lens conditions, the mean rating of overall performance in the simulator with the *Acuvue bifocal* was 4.11 (sd=1.43), with the *Bausch & Lomb multi-focal* was 4.57 (sd=1.52), and with the *Ciba progressive* was 3.83 (sd=1.41). Pilot ratings of performance with each of the three contact lenses was statistically significantly worse than with the bifocal spectacles ($p<0.001$). See Figure 7.

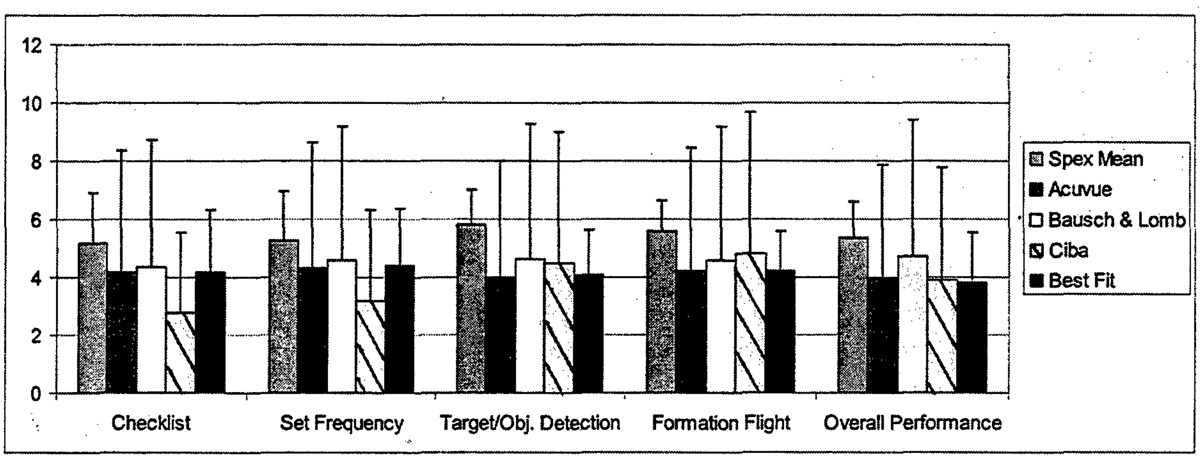

Figure 7. Pilot ratings of performance of bifocal spectacles and multifocal contact lenses on simulator tasks.

Current lenses (contact lenses) compared to spectacles

Pilot ratings comparing each contact lens to the bifocal spectacles in the performance of tasks in the simulator was 3.04 (sd=0.33) for the *Acuvue bifocal*, 3.39 (sd=0.74) for the *Bausch & Lomb multi-focal* and 2.83 (sd=1.31) for the *Ciba progressives.* These ratings indicate a general consensus that all of the multifocal contact lenses were "slightly worse" than the bifocal spectacles. See Figure 8.

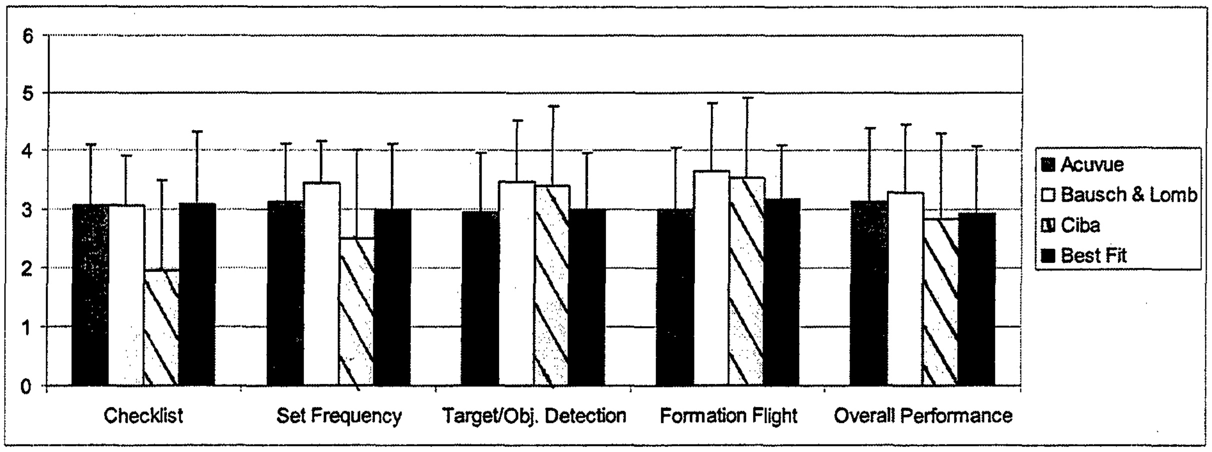

Figure 8. Pilot ratings of relative performance of each multifocal contact lens compared to bifocal spectacles on simulator tasks (5 indicates "same as spectacles" – lower values indicate "worse than spectacles").

Discussion

One of the objectives of this study was to determine whether new generation multifocal contact lens designs show potential to provide adequate vision compatible with the basic occupational tasks and environmental conditions unique to Army aviators. Through evaluation of visual performance, flight performance and subjective assessment of the three types of contact lenses compared to spectacle correction in this study, the best option for presbyopic aviators continues to be either bifocal spectacles or "readers." Multifocal contact lenses provide a lesser level of visual performance over all measures, especially low luminance and low contrast near vision. When the contact lens fit that provides 20/20 distance and near vision is considered, only 12 of the 18 pilots were considered adequately fit. Within this subgroup, visual performance with the contact lenses was more in keeping with spectacle visual performance and tended to meet flight standards for vision (the only established standards are distance and near high contrast visual acuity and depth perception). This indicates that with careful fitting, some pilots could be successfully fit in multifocal contact lenses for aviation duties.

For performance of flight duties in a daytime environment, performance did not show a decrement. Overall, flight performance was best with the *Bausch & Lomb multi-focal* contact lens. Although not statistically significant, flight performance with the *Bausch & Lomb multi-focal* scored higher than *bifocal spectacles.* It should be noted, however, that this flight performance assessment was completed in a simulator and does not represent the full spectrum of flying duties of an Army aviator.

Another objective of the study was to determine whether there was a general trend towards acceptance of a binocular multifocal contact lens fit. This was not directly assessed, however, of the eighteen subjects, nine requested a prescription for one of the contact lenses for continued personal use. These prescriptions are indicated in bold in Appendix D.

As to whether any of the new generation contact lenses were strongly preferred or strongly rejected by the small pilot sample, there was no evident trend. Assessments indicated that of the three lenses overall, *Ciba progressives* provided the best distance visual performance levels, while *Acuvue bifocal* gave the best near visual performance levels. The survey of pilots showed the overall ability to fly the aircraft was easiest with *bifocal spectacles* in all areas. In 5 of the 6 areas rated, the *Bausch & Lomb multi-focal* contact lens scored higher by subjective assessment than the *Acuvue bifocal* and the *Ciba progressive* lenses.

Studies specific to the Apache flight environment are being considered, since visual performance remained within norms and Apache pilots are faced with greater interface problems with bifocal spectacles, head-mounted displays and protective mask configurations than pilots in other aviation platforms. Many Apache pilots have been permanently grounded or converted to other platforms due to the onset of presbyopia and spectacle incompatibility issues in the cockpit.

References

Bailey, I. L., Bullimore, M.A., Raasch, T.W.,Taylor, H.R. 1991. Clinical grading and the effects of scaling. Investigative Ophthalmology and Visual Science. 32(2): 422-32.

Bailey, I. L. and Lovie J. E. 1976. New design principles for visual acuity letter charts. American Journal of Optometry and Physiological Optics. 53(11): 740-5.

Haegerstrom-Portnoy, G., Brabyn, J., Schneck, M.E., Jampolsky, A. 1997. The SKILL Card. An acuity test of reduced luminance and contrast. Smith-Kettlewell Institute Low Luminance. Investigative Ophthalmology and Visual Science. 38(1): 207-18.

Lattimore, M. R., Jr. 1992. Contact lenses in the U.S. Army attack helicopter environment: an interim report. Journal of the American Optometric Association. 63(5): 322-5.

Lattimore, M. R., Jr. and Schrimsher R. H. 1993. Refractive error distribution and incidence among U.S. Army aviators. Military Medicine. 158(8): 553-6.

Morse, S. E. and Reese, M.A. 1997. The use of bifocal soft contact lenses in the Fort Rucker aviation environment. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 97-27.

Nakagawara, V. B. and Veronneau, S. J. 2000. Monovision contact lens use in the aviation environment: a report of a contact lens-related aircraft accident(1). American Journal of Ophthalmology. 130(4): 542-3.

Appendix A.

Multifocal Contact Lens Study
Flight Profile and Score Sheet

Date ________ **Subject** _____

Run ID _________ **Simulator Operator Initials** ______

TASK	TASK DESCRIPTION	HDG/TRACK (DEGREES)	ALTITUDE (FEET)	AIRSPEED (KIAS)	SCORE 1	2	3	4	5
1	IGE Right Hovering Turn (360)	060 - 060	10 AGL	0					
2	VMC Takeoff (500fpm) Upwind Leg	060	0 AGL - 1000 MSL	0 - 80					
3	Straight and Level Downwind Leg/ **Emergency Procedure ☐ if checked**	240	1000 MSL	100					
4	Turn/Decelerating/Descent Base Leg	240 - 330	1000 MSL - 700 MSL	100 - 80					
5	VMC Approach (500fpm) Final Leg	060	700 MSL - 0 AGL	80 - 0					
6	VMC Takeoff (500fpm) Upwind Leg	060	0 AGL - 1000 MSL	0 - 80					
7	Straight and Level Downwind Leg/ **Emergency Procedure ☐ if checked**	240	1000 MSL	100					
8	Turn/Decelerating/Descent Base Leg	240 - 330	1000 MSL - 700 MSL	100 - 80					
9	VMC Approach (500fpm) Final Leg	060	700 MSL - 0 AGL	80 - 0					
10	Formation Flight								
11	Admin Vectors to ILS/ **Emergency Procedure**								
12	ILS Rwy 6 (OZR) ***Set ceiling to 250'**	61	2000 MSL - 498 MSL	120					

*Run ID = Subject Number (first 2 digits); Lens Type (01 = Multifocal Spex first run; 02 = Multifocal Spex second run; 11 = lens 1; 12 = lens 2; 13 = lens 3); Run sequence (1 thru 6 for first through sixth run in the simulator)

Appendix B.

Surveys.

Date: ______________ Approximate hours in UH-60 aircraft/in all aircraft _____/_____

Subject ID: _________ Approximate hours in UH-60 simulator ________

Bifocal Type (to be filled in by research staff) ✍ _________________________________

____

Check the number that most closely matches your evaluation of your **Bifocal Spectacles**

	Very Difficult	Moderately Difficult	Slightly Difficult	Neither Difficult nor Easy	Slightly Easy	Moderately Easy	Very Easy
Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Read Checklist							
Set Frequency							
Target/object detection							
Formation Flight							
Overall performance							

Comments?

Multifocal Contact Lens Questionnaire

Date: ____________ Approximate hours in UH-60 aircraft/in all aircraft _____/_____

Subject ID: ________ Approximate hours in UH-60 simulator _________

Multifocal Type (to be filled in by research staff) ✍ ____________________________

Part 1. Check the number that most closely matches your evaluation of your **Current Lenses**

	Very Difficult	Moderately Difficult	Slightly Difficult	Neither Difficult nor Easy	Slightly Easy	Moderately Easy	Very Easy
Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Read Checklist							
Set Frequency							
Target/object detection							
Formation Flight							
Overall performance							

Part 2. Check the number that most closely matches your evaluation of the **Current Contact Lenses Compared to your Bifocal Spectacles.**

	Much Poorer	Moderately Poorer	Slightly Poorer	Same as Glasses	Slightly Better	Moderately Better	Much Better
Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Read Checklist							
Set Frequency							
Target/object detection							
Formation Flight							
Overall performance							

Part 3. During any portion of this simulator evaluation, did you experience difficulties because of the contact lenses? Yes/ No

If yes, please describe (continue on the back if needed)

Date ________________ Subject ID ______________

Part 4. General Wear Questions

1. What is your age? _________

2. Have you ever worn contact lenses before this study? Yes/No
   If yes, were they Single Vision or Multifocal? ____________

3. How many hours did you wear the contact lenses each day?

Day 1 _____ Day 2 _____ Day 3 _____ Day 4 _____ Day 5 _____ Day 6 _____ Day 7 _____

4. Did you experience any difficulty handling the contact lenses?

Putting them in? Yes/No Removing them? Yes/No

5. Did you experience any "settling" of the contacts after you first put them in your eyes? Yes/No
   If yes, how long was the "settling" period? (Check one of the boxes below)

Less than 5 minutes	5-10 minutes	11-30 minutes	31-60 minutes	1 hour or more

6. Did you experience any fluctuation in your vision while wearing the contact lenses? Yes/No

7. Did you have to remove the contact lenses for any reason? Yes/No (if no, skip to #8)
   If yes, please state the reason(s):

8. Please rate the following using the 1-7 scale.

	Very Bad	Moderately Bad	Slightly Bad	Neither Good nor Bad	Slightly Good	Moderately Good	Very Good
Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Distance vision							
Near vision							
Comfort							
Vision during the day							
Vision at night							
Overall performance of daily activities							

9. How comfortable would you feel wearing these contact lenses in the cockpit? (Scale of 1-7, with 1 being VERY UNCOMFORTABLE to 7 being VERY COMFORTABLE)

1 2 3 4 5 6 7

10. Any additional comments (continue on the back, if needed).

Appendix C.

Demographics.

Part 1.

Subject Number	Age	Aircraft	Pupil Sizes			
			High Luminance (100 cd/m²)		Low Luminance (3 cd/m²)	
			OD	OS	OD	OS
001	57	OH-58/TH-67	2.3	2.4	6.3	6.5
003	55	OH-58/TH-67	3.1	3.2	5.4	6.0
004	49	AH-64	2.9	2.8	6.6	6.5
005	56	C-12/TH-67	2.2	2.3	7.3	6.8
007	49	UH-1/UH-60	2.2	2.2	6.6	6.4
008	54	UH-1	1.9	1.7	4.5	4.4
009	46	OH-58	2.2	2.4	5.3	5.4
011	54	UH-60	2.1	2.1	4.1	4.8
012	47	UH-60/UH-1	2.6	3.0	7.3	7.7
013	48	UH-60	1.9	2.4	6.6	6.3
014	56	CH-47	2.0	2.3	5.2	5.2
015	46	UH-1/UH-60	2.3	2.5	6.0	6.3
016	50	AH-64	3.7	4.0	5.7	5.8
018	57	UH-60	2.3	2.6	6.8	7.3
019	56	AH-64	2.2	2.3	7.8	6.9
020	60	TH-67	2.1	2.1	5.2	5.3
021	46	TH-67	2.5	2.5	5.0	5.0
022	44	TH-67/OH-58	3.5	3.5	7.0	6.5

Demographics.

Part 2.

Subject Number	Refractive Error						
	OD			OS			ADD
	SPH	CYL	AXIS	SPH	CYL	AXIS	
001	+2.50	-0.75	146	+1.25	-0.75	095	2.50
003	+0.75	-0.50	070	+0.50	-0.75	096	2.00
004	-1.25	-0.50	117	-1.50	-0.25	093	1.75
005	-1.00	-0.50	068	-0.25	-1.00	096	2.25
007	+0.25	-0.25	118	+0.25	-0.50	091	2.00
008	0.00	-0.25	142	0.00	-0.25	044	1.75
009	+0.75	-0.50	101	+1.00	-0.75	086	1.25
011	+0.50	-0.25	130	+0.75	sphere		2.25
012	+0.25	-0.25	085	+0.25	-0.25	111	1.00
013	+0.25	-0.25	110	0.00	-0.25	050	1.75
014	+2.50	-0.75	090	+2.00	-0.75	105	2.25
015	0.00	-0.50	180	0.00	-0.50	180	1.75
016	+1.00	-0.50	100	+0.50	-0.50	085	2.00
018	0.00	-0.50	090	+1.25	-1.50	078	1.75
019	-1.75	-0.25	020	-1.50	-0.25	102	2.00
020	+2.00	sphere		+1.75	sphere		2.50
021	0.00	sphere		-0.25	-0.75	075	0.00
022	-0.50	-0.50	084	-0.50	-0.50	095	1.00

Appendix D.

Contact lens parameters.

Subject Number	Contact Lens Parameters					
	Acuvue 8.5 BC, 14.2 Dia. Add range +1.00 to +2.50		Bausch & Lomb 8.5 or 8.8 BC, Add High		Ciba 8.6 BC, 14.0 Dia. Add is standard	
	OD	OS	OD	OS	OD	OS
001	+2.25/ +2.00 Add	+1.00/ +2.00 Add	**+2.25/ 8.5 BC**	**+1.00/ 8.5 BC**	+2.25	+1.00
003	+0.00/ +1.50 Add	-0.50/ +1.50 Add	**+0.00/ 8.8 BC**	**-0.75/ 8.8 BC**	+0.25	-0.25
004	-1.50/ +2.00 Add	-1.50/ +2.00 Add	-1.50/ 8.8 BC	-1.50/ 8.8 BC	-1.75	-1.75
005	-1.00/ +2.50 Add	-0.50/ +2.50 Add	-1.00/ 8.8 BC	-0.50/ 8.8 BC	-1.00	-0.75
007	+0.00/ +1.50 Add	+0.00/ +1.50 Add	+0.00/ 8.5 BC	+0.00/ 8.5 BC	+0.25	+0.25
008	-0.25/ +2.50 Add	-0.25/ +2.50 Add	+0.00/ 8.8 BC	+0.00/ 8.8 BC	+0.50	+0.50
009	+0.50/ +1.50 Add	+0.75/ +1.50 Add	**+0.50/ 8.8 BC**	**+0.75/ 8.8 BC**	+0.75	+1.00
011	+0.00/ +2.00 Add	+0.00/ +2.00 Add	**+0.00/ 8.5 BC**	**+0.25/ 8.5 BC**	+0.75	+0.75
012	+0.00/ +1.00 Add	+0.00/ +1.00 Add	-0.50/ 8.8 BC	-0.25/ 8.8 BC	**+0.25**	**+0.25**
013	+0.00/ +1.50 Add	+0.00/ +1.50 Add	+0.00/ 8.8 BC	+0.00/ 8.8 BC	+0.25	+0.00
014	+2.25/ +2.50 Add	+1.75/ +2.50 Add	+2.25/ 8.5 BC	+1.75/ 8.5 BC	+2.75	+2.00
015	**-0.25/ +1.50 Add**	**-0.25/ +1.50 Add**	-0.50/ 8.8 BC	-0.25/ 8.8 BC	-0.25	+0.00
016	+0.75/ +2.00 Add	+0.50/ +2.00 Add	+0.50/ 8.8 BC	+0.25/ 8.8 BC	+1.00	+0.50
018	-0.25/ +2.00 Add	-0.50/ +2.50 Add	-0.25/ 8.8 BC	-0.50/ 8.8 BC	+0.00	+0.75
019	-1.75/ +2.00 Add	-1.50 +2.00 Add	-1.75/ 8.8 BC	-1.50/ 8.8 BC	**-1.50**	**-0.75**
020	+2.25/ +2.50 Add	+2.25/ +2.50 Add	+2.25/ 8.8 BC	+2.25/ 8.8 BC	**+2.50**	**+2.50**
021	+0.00/ +1.50 Add	-0.25/ +1.50 Add	+0.00/ 8.8 BC	-0.50/ 8.8 BC	+0.00	-0.25
022	-0.75/ +1.50 Add	-0.75/ +1.50 Add	-0.75/ 8.8 BC	-0.75/ 8.8 BC	**-0.75**	**-0.75**

Appendix E.

Multifocal contact lens study score sheet.

Bifocal Contact Lens Study

Pt ID# : ____________ **Birth Date:** ____________

Exam Date : ____________ **M / F**

Visit: Lens 1 / Lens 2 / Lens 3 — Spectacles — Modified Monovision

Manifest Refraction:	Sphere	Cylinder	Axis	DHCVA	ADD	NHCVA
OD	____	____	____	20/ ____		14/ ____
OS	____	____	____	20/ ____		14/ ____

UCVA:	OU	____	# of letters read incorrectly	____	logMAR
HCVA:	OU	____	# of letters read incorrectly	____	logMAR
LCVA:	OU	____	# of letters read incorrectly	____	logMAR
LCVA (filter):	OU	____	# of letters read incorrectly	____	logMAR
LCVA (glare):	OU	____	# of letters read incorrectly	____	logMAR
SKILL (light):	OU	____	# of letters read incorrectly	____	logMAR
SKILL (dark):	OU	____	# of letters read incorrectly	____	logMAR

(add 10 letters to compute)

RANDOT Stereo: ____ seconds of Arc

Dynamic Stereopsis (Pulfrich): Ellipse seen? Yes // No
Back of Ellipse? Right to left // Left to right

Pupil Size:		OD	OS
	High Luminance:	____ mm	____ mm
	Low Luminance:	____ mm	____ mm

Slit lamp Exam	OD	OS
L/L		
Cornea		
Conj		
Contact Lens		
Centration		
Movement		
Surface		

Appendix F.

Multifocal contact lens study score sheet.

Bifocal Contact Lens Study
Contrast Sensitivity and NVG Tests

Pt ID#____________________ **Birth Date:**__________________

Exam Date:__________________ **M / F**

Visit: **Lens 1** **Spectacles**
Lens 2
Lens 3 **Modified Monovision**

Computer Contrast Sensitivity

	1	2	4	8	16
Normal CS (hi):					
Normal CS (lo): ***w/ Screen Filter***					

Depth-Normal

without NVG's
Far--> 12

A	B	C	D	E	F
3	3	4	3	2	3
2	4	2	2	3	2
4	2	4	3	4	2
83	43	32	27	19	13

Score:________