MILITARY MEDICINE, 175, 3:197, 2010

Corrective Lens Use and Refractive Error Among United States Air Force Aircrew

Steve T. Wright, OD, MS; Douglas J. Ivan, MD; Lt Col Patrick J. Clark, USAF BSC; Col (s) John M. Gooch, USAF MC SFS; William Thompson, MS

ABSTRACT Corrective lens use by military aviators is an important consideration in the design of head-mounted equipment. The United States Air Force (USAF) has periodically monitored lens use by aviators; however, it has been over a decade since the last study. We provide an update on the prevalence of corrective lenses and refractive error among USAF aircrew based on eyeglass orders processed through the Spectacle Request Transmission System (SRTS). Currently, 41% of active duty USAF pilots and 54% of other aircrew require corrective lenses to perform flight duties. Refractive errors are characterized by low to moderate levels of myopia with a mean spherical equivalent power of −1.01 diopters (D) for pilots and −1.68 D for others. Contact lenses, and more recently refractive surgery, reduce the number of aircrew that must rely on spectacles when flying; however, spectacle compatibility remains an important consideration in the cockpit.

INTRODUCTION

The United States Air Force (USAF) has historically taken an interest in identifying the number of aircrew, most notably pilots, required to wear corrective lenses for flying duties. Information on the prevalence of spectacle wear is an important consideration when designing modern avionics systems and life support equipment worn in the cockpit. There is an inherent need for human systems integration to assure spectacle compatibility early in many program life cycles to avoid seeking last minute solutions.[1] This information is also required to assess the impact of changes made in aeromedical policy and vision standards related to ametropia both in trained aviators and aircrew candidates. Additionally, it provides insight into the magnitude of aeromedical support needed for aviators, e.g., optical laboratory fabrication of aircrew frames and lenses, soft contact lens fittings, laser eye protection, and corneal refractive surgery (CRS) procedures.

The Aerospace Ophthalmology Branch of the USAF School of Aerospace Medicine (USAFSAM) has periodically conducted studies to provide accurate data regarding corrective lens use and refractive status among the aviator population. To date, there have been four major efforts to quantify these attributes, Table I, and each has reported this figure to be steadily rising despite the challenges associated with fitting and wearing lens correction for flying activities,[2–5] including some that are potentially mission or life threatening.[6] There may be numerous factors that have contributed to the rise in ametropia among aircrew, but one of particular importance has been the incremental relaxation of vision and refractive error standards required for USAF aircrew applicants, exemplified by the changes to pilot applicant standards reported in Table II.

United States Air Force School of Aerospace Medicine, 2507 Kennedy Circle, Brooks City-Base, TX 78234.

Currently, the percentage of USAF aviators required to use corrective lenses for flying is not known. In 1969, Dunsky reported that 17% of pilots and 29% of navigators required corrective lenses,[7] while a study by Provines in 1980 placed these figures at 20% and 50%, respectively.[8] In 1990, Miller reported that 27% of pilots, 52% of navigators, and 40% of other aircrew used corrective lenses for flying duties,[9] and by the 1995 Aircrew Operational Vision Survey (AOVS) these findings had increased to 39%, 64%, and 53%.[10] Since 1995, vision standards for USAF pilot applicants have been relaxed and recent policy changes have allowed higher degrees of hyperopia (up to 4.00 D), as well as astigmatism and myopia (up to 3.00 D each), to be considered for waiver. Additionally, USAF policy now allows trained aircrew and aircrew applicants to pursue CRS, although with limitations on the degree of preoperative refractive error. The impact of these changes has yet to be determined.

This study reports data on the current prevalence of corrective lens use and the magnitude of refractive errors among active duty USAF pilots and several other aircrew positions, including navigators, air battle managers, flight surgeons, in-flight refuelers, flight engineers, and loadmasters.

METHODS

The study protocol was approved as exempt by the Wright-Patterson Air Force Institutional Review Board and no human subjects were contacted in the process of data collection. Corrective lens use was based on eyeglass orders filled by the Department of Defense (DoD) Optical Fabrication Enterprise as reported in the Spectacle Request Transmission System (SRTS) database. Aircrew that do not meet uncorrected distant and near visual acuity standards (20/20 or better with each eye) or uncorrected stereopsis standards (25 arc seconds) must use corrective lenses while flying. If spectacles are required, the individual must use USAF approved aircrew frames, which are ordered through SRTS. Alternatively, if

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
MAR 2010		**00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Corrective Lens Use and Refractive Error Among United States Air Force Aircrew	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Air Force School of Aerospace Medicine,2507 Kennedy Circle,Brooks City-Base,TX,78234**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

qualified, the individual may participate in the USAF Aircrew Soft Contact Lens Program; however, they are still required to maintain a current pair of back-up aircrew spectacles on person at all times when flying. Again, these would be ordered through SRTS.

Aircrew were selectively identified within SRTS on the basis of their Air Force Specialty Code (AFSC), a job classification code assigned to all members of the Air Force. Many individuals carry more than one AFSC, particularly if their duty and assignment history span several disciplines or areas of responsibility. For example, a fighter pilot who is also a wing commander might be assigned a primary AFSC (PAFSC) of 11F (where "11" designates pilot and "F" designates fighter) as well as a duty AFSC (DAFSC) of 92W (for wing commander). Our analysis was based on the PAFSC. To determine the percentage of aircrew utilizing lens correction, the total number of aircrew at each crew position, again based on PAFSC, was determined from USAF personnel records.

TABLE I. Historical Incidence of Corrective Lens Use by USAF Aircrew

		% Using Corrective Lenses		
Year of Study	Lead Author	Pilot	Nav	Flight Surgeon
1969	Dunsky	17.0	29.0	NA
1980	Provines	19.6	50.0	NA
1990	Miller	27.4	51.5	NA
1995	Baldwin	39.4	63.6	78.0

Nav, navigator; NA, data not reported.

TABLE II. Historical Refractive and Acuity Standards for Pilot Applicants Based on Mode of Entry

Year	Mode of Entry	Myopia	Uncorrected Acuity
Pre 1975	All	−0.25	20/20
1980	(OTS)	−0.25	20/20
	(AFA/ROTC)	−1.25	20/50
1990	(OTS)	−0.25	20/20
	(AFA/ROTC)	−1.50	20/70
1996	(All)	−1.50	20/70

OTS, Officer Training School; AFA, Air Force Academy; ROTC, Reserve Officer Training Corps.

Although the SRTS database includes spectacle orders for the time period September 1998 to April 2008 (when the database query was performed), this was not a longitudinal study as only current USAF aircrew were considered. Aircrew that had previously ordered spectacles, but had since retired or separated from the military, were not included in this analysis. Thus, a snapshot of the most recent spectacle orders for the current aircrew population is reported. Additionally, this study was further limited to active duty members on the basis of preliminary findings that suggested using SRTS data for Air Force Reserve Component (AFRC) and Air National Guard (ANG) was unreliable. Specifically, eyeglass orders for AFRC and ANG aircrew were reported at a rate nearly 50% lower than their active duty counterpart despite the fact that, on average, AFRC and ANG aircrew were more than 5 years older. Given that AFRC and ANG aircrew are held to the same vision standards as active duty, and the fact that Miller's survey in 1990 as well as the data compiled from our study consistently show that corrective lens prevalence for aircrew increases with increasing age, it was postulated that AFRC and ANG do not utilize the SRTS system with a consistency to provide meaningful findings.

RESULTS

Lens Prevalence

USAF personnel records identified 23,218 active duty aircrew with a PAFSC for the crew positions being studied, of which 10,898 were identified in the SRTS database as having placed orders for aircrew spectacles between November 1999 and March 2008. This equated to an overall prevalence of 46.9%. Pilots represented the largest single crew position with 12,951 members and had the lowest spectacle prevalence at 41.0%. Corrective lens use was the most prevalent among flight surgeons at 75.4%. Lens prevalence for all crew positions are outlined in Table III.

Refractive Error Distribution

Myopia correction was the dominant lens power found among aircrew spectacles, accounting for 82% of orders for pilots and 83% for all other aircrew. Pilot refractive errors were typically lower in magnitude, averaging −1.01 D, with 83% of the

TABLE III. Prevalence of Corrective Lens Use by Aircrew Position

Crew Position	PAFSC	Total	No. Using Lenses	% Using Lenses	Median Age	Age Range
Pilot	11	12,951	5,312	41.0	32.6	21–60
Navigator	12	3,768	2,147	57.0	36.2	22–60
Air Battle Manager	13	1,504	912	60.6	33.1	22–61
Flight Surgeon	48	609	459	75.4	40.9	27–63
In-Flight Refueler	1A0	732	310	42.3	26.9	19–47
Flight Engineer	1A1	1,283	716	55.8	35.9	20–57
Loadmaster	1A2	2,371	1,042	43.9	28.9	18–51
Total		23,218	10,898	46.9	33.3	18–63

PAFSC, Primary Air Force Specialty Code.

lenses ordered falling between +2.00 D and −2.00 D, based on spherical equivalent (SE) power. Orders for other aircrew members averaged −1.68 D and fell within +2.00 D and −2.00 D 62% of the time.

Correction of higher amounts of myopia was infrequent among pilots with only 6% of lenses ordered being above −3.00 D and less than 2% being over −4.00 D. In contrast, orders for nonpilot aircrew were above these criteria in 21% and 12% of orders, respectively. The overall distribution of SE refractive errors for pilot and other aircrew positions are plotted in Figure 1 and are described in greater detail in Table IV.

Astigmatic correction was also common, observed in 70% of pilot spectacle orders and 74% of nonpilot orders; however, the magnitude of astigmatism was generally low, averaging 0.53 D for pilots and 0.63 D for other aircrew. Astigmatism is an important consideration when evaluating refractive errors among aviators as the presence of higher amounts of astigmatism may preclude the use of soft contact lenses due to unacceptable or unstable visual acuity. On the basis of this consideration, several key levels of astigmatism were noted as follows:

- 67% of pilots and 62% of other aircrew had astigmatism of 0.50 D or less. These individuals would be ideal candidates for spherical soft contact lenses.
- 31% of pilots and 34% of other aircrew had astigmatism between 0.75 D and 2.00 D, likely requiring toric contact lens correction.
- Astigmatism greater than 2.00 D was observed infrequently, accounting for only 2% of pilot and 4% of nonpilot spectacle orders. Achieving acceptable and stable visual acuity using soft contact lenses with this degree of astigmatism is problematic. This concern is reflected in USAF policy, which requires an aeromedical waiver for any aircrew member using contacts with more than 2.00 D of toricity.

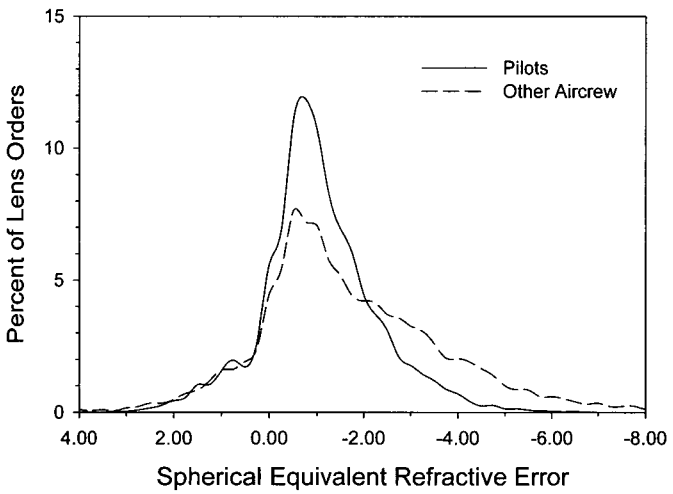

FIGURE 1. Distribution of spherical equivalent refractive errors reported in aircrew spectacle orders.

Lens Modality and Prevalence Based on Aircrew Age

The prevalence of corrective lens use based on age followed a similar trend for both pilot and nonpilot aircrew members (Fig. 2). From ages 25 to 45, the use of lenses gradually increased as a function of age. Above age 45, there was a marked inflection point toward more frequent lens use due to the onset of presbyopia. In the relatively younger population, spectacle orders were consistently higher among nonpilots; however, in subjects 46 and older, the prevalence was very similar between the two populations.

Bifocal lenses accounted for 14.8% of spectacle orders for all aircrew members; a small decrease from the 1995 survey, which identified 17.8% of aircrew using bifocals. As expected, the prevalence of bifocal lenses was associated with the age of the subject, and in particular, was highest among flight surgeons (37.7%), whereas in-flight refuelers (7.7%) and loadmasters (8.2%) had the lowest prevalence of bifocal lens orders. The bifocal prevalence among active duty pilots was 12.2%.

Lens Prevalence Based on Primary Airframe (Pilots Only)

The prevalence of corrective lens use among pilots was determined on the basis of their assigned airframe and categorized among four groups: fighters, bombers, mobility and others (which included training aircraft, rotary wing aircraft, unmanned aircraft, special ops, and test pilots). As shown in Figure 3, lens use was observed most frequently among pilots of the others group (43.4%) followed by fighter and mobil-

TABLE IV. Percentages of Spherical Equivalent Refractive Errors by Aircrew Position

Spherical Equivalent (Diopters)	Pilot	Navigator	Air Battle Manager	Flight Surgeon	In-Flight Refueler	Flight Engineer	Loadmaster	Total
+4.00 and Above	<0.1	<0.1	0.9	0.5	<0.1	<0.1	0.3	0.1
+3.00 to +3.99	<0.1	0.3	0.7	0.2	0.3	0.3	0.3	0.2
+2.00 to +2.99	0.6	1.1	1.5	2.3	1.0	0.7	2.4	1.0
+1.00 to +1.99	4.0	4.1	3.8	7.1	2.9	2.8	5.4	4.1
+0.99 to −0.99	46.0	33.3	26.6	27.1	39.8	36.9	37.0	39.4
−1.00 to −1.99	30.1	24.8	16.1	16.8	19.7	23.2	19.8	25.7
−2.00 to −2.99	12.4	18.0	13.5	14.2	12.6	13.9	13.8	13.9
−3.00 to −3.99	5.0	11.6	11.7	10.1	12.4	9.1	8.4	7.9
−4.00 and Above	1.9	7.0	25.2	21.7	11.3	13.2	12.6	7.8

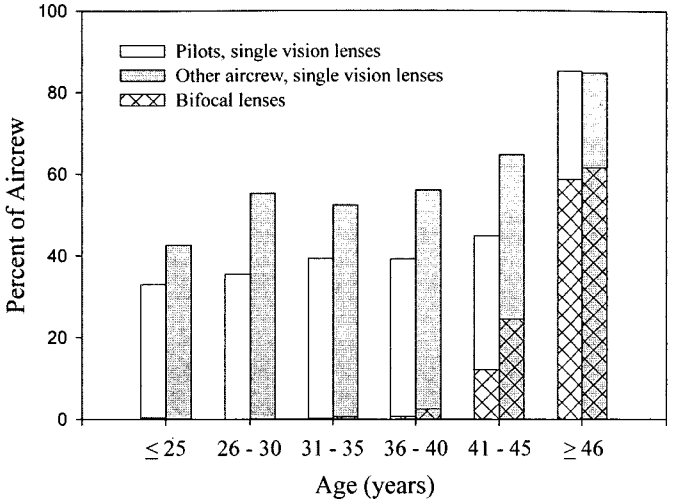

FIGURE 2. Lens prevalence and type of corrective lens based on aircrew age.

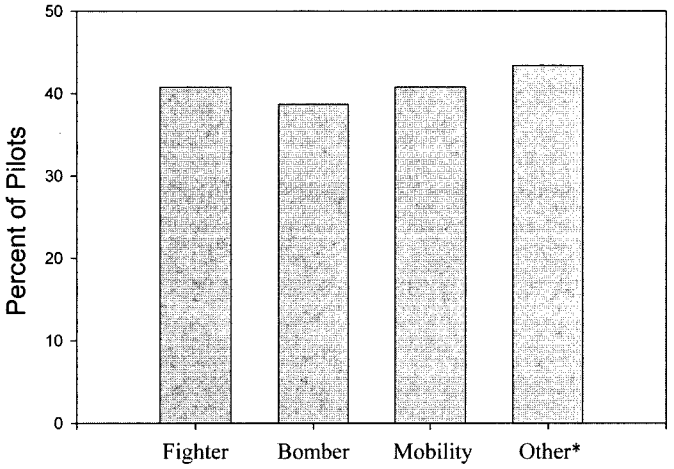

FIGURE 3. Corrective lens prevalence for pilots based on primary airframe.

ity (both 40.8%) and was least frequent among bomber pilots (38.7%). Despite the apparent consistency, these differences were statistically significant, χ^2 (3; 12,951) = 11.04, $p = 0.011$ (SPSS, Chicago, IL) with the others group being the origin of these differences. When lens prevalence was compared with the others group removed from the analysis, no significant differences in lens use between airframes was found, χ^2 (2; 10,410) = 4.00, $p = 0.135$. It was suspected that the basis of these differences may lie in age discrepancies between pilots of the others group (median age 34.5 years) relative to their fighter, bomber, mobility counterparts (median age 32.0 years). However, no statistical model would support this hypothesis, so the basis for the differences remains unclear.

DISCUSSION

On the basis of spectacle orders from the SRTS database, the prevalence of corrective lens use among current USAF aircrew members has remained relatively constant compared to the most recent survey in 1995. One should keep in mind, however, that these two studies were very different in their methodologies and a direct comparison should not be made without this consideration. Our results do suggest, however, that analysis of SRTS data provides a highly efficient manner of estimating the prevalence of corrective lenses and refractive errors among USAF aircrew without the need for expensive and time-consuming surveys or record reviews. We are encouraged by the consistency of results that SRTS data have provided relative to the more comprehensive study in 1995, but at a fraction of the time and cost.

Despite successful use of spectacles by aircrew for decades,[11–13] spectacle use in military aviation presents numerous operational liability and compatibility issues, especially in high-performance aircraft. The 1995 AOVS reported that 56% of aircrew were dissatisfied with the standard issue HGU-4/p aircrew frame, citing problems with discomfort, fogging of lenses, and reduced peripheral vision. The same survey reported that 51% of aircrew experienced spontaneous loss of a lens, with 22% reporting lens loss in flight (some on more than 10 occasions). Spectacle compatibility problems with existing life-support equipment were also noted by one in five aircrew members. The HGU-4/p frame was even implicated in several aircraft mishaps. Consequently, these safety and functional problems resulted in a complete redesign of the aircrew frame[14] and replacement of the HGU-4/p with the Air Force flight frame (AFF) in 2000. This appears to have successfully addressed many of the problems previously identified; however, compatibility continues to be a challenge with emergent helmet/mask/visor ensembles. A prime example is the Joint Helmet Mounted Cueing System (JHMCS) being developed for F-15, F-16, and F-18 pilots. The JHMCS provides an in-helmet head up display that allows the pilot to direct, or "cue," on-board weapons systems against enemy aircraft merely by pointing their head toward the target. Unfortunately, this configuration limits the available space beneath the visor resulting in integration challenges with spectacles, including the AFF. As a result, the AFF has been modified into a special variant, the AFF-JS, to accommodate this system and others with similar constraints, such as the helmet ensemble under development for the joint strike fighter (JSF/F-35).

Refractive errors among aircrew using lens correction are for the most part characterized by relatively low levels of myopia and astigmatism. These refractive error attributes make many aircrew members optimal candidates for both soft contact lens correction and corneal refractive surgery. Soft contact lenses have been approved for USAF flying duties since 1989. The 1995 AOVS found that 29% of aircrew using lenses for flying duties utilized contact lenses and 98% of these individuals reported them to be operationally advantageous over spectacles. A 2007 survey of nearly 1,000 USAF pilots wearing correction for flying duties reported 62% used contact lenses in place of spectacles when flying.[15] Refractive surgery was approved for aircrew members in August 2000. Initially only photorefractive keratectomy (PRK) was approved, but

more recently USAF aeromedical policy was expanded to include approval for laser in-situ keratomileusis (LASIK), although USAF policy limits CRS treatments on aircrew to no more than 8.00 D of myopia, no more than 3.00 D of astigmatism, and no hyperopic treatments. A cursory analysis of refractive errors among aircrew members reveals over half of this population fall within the refractive limits allowable for surgical treatment. However, other factors such as personal preferences, refractive instability, ocular pathology, or systemic health may preclude this option for some individuals. Nonetheless, as many as 6,000 potential refractive surgery candidates among the current active duty USAF aviation population exist. As of July 2008, 1,450 aircrew have been surgically treated since the program started, but only 950 of these remain on active duty. Certainly high interest in CRS exists among USAF aviators. In a recent aircrew survey, 89% of lens-wearing USAF pilots indicated that they would like to pursue refractive surgery and 72% plan to seek treatment within the USAF program.[15] These same pilots noted, however, that pursuing CRS as an active duty flyer is difficult due to the current operational tempo, which often prohibits elective procedures that could potentially ground an aviator for an extended period of time. In addition, many expressed concerns about the potential risk of decreased night vision or quality of vision after CRS that could negatively impact their career in military aviation.

CONCLUSION

Corrective lenses are highly prevalent among USAF aircrew, including pilots. Currently, 41% of active duty pilots and 54% of nonpilots require lens correction. Soft contact lenses, and to a lesser degree refractive surgery, reduce the number of aircrew that must rely exclusively on spectacles for refractive error correction. However, there still remains a significant number of aircrew that continue to require spectacles as either their primary or secondary modality. Therefore, spectacles will remain an important part of military aviation and will continue to present integration challenges as life-support equipment, laser eye protection, helmets, masks, and other head-mounted devices are developed. Additionally, the SRTS database proved a useful tool to monitor corrective eyewear trends in military aircrew.

ACKNOWLEDGMENTS

The authors thank Dr. James Leonard and Dr. Rebecca Myatt for their technical support in accessing the Spectacle Request Transmission System database.

REFERENCES

1. Lattimore M, Cornum R: The Use of Extended Wear Contact Lenses in the Aviation Environment. September Report No. 92-35. Fort Rucker, AL, U.S. Army Aeromedical Research Laboratory, 1992.
2. Miller R II, Kent J, Green R: Prescribing spectacles for aviators: USAF experience. Aviat Space Environ Med 1992; 63: 80–5.
3. Nakagawara V, Wood K, Montgomery R: Vision Impairment and Corrective Considerations of Civil Airmen. Report No. DOT/FAA/AM-93/21. Washington, DC, Office of Aviation Medicine, December 1993.
4. Nakagawara V, Montgomery R, Wood K: Demographics and Vision Restrictions in Civilian Pilots: Clinical Implications. Report No. DOT/FAA/AM-04/6. Washington, DC, Office of Aviation Medicine, April 2004.
5. Partner A, Scott R, Shaw P, Coker W: Contact lenses and corrective flying spectacles in military aircrew: implications for flight safety. Aviat Space Environ Med 2005; 76: 661–5.
6. Nakagawara V, Montgomery R, Wood K: Aviation Accidents and Incidents Associated with the Use of Ophthalmic Devices by Civilian Airmen. Aviat Space Environ Med 2002; 73: 1109–13.
7. Dunsky I, Levene J: Analysis of Some Refractive Error Trends in US Air Force Pilots and Navigators. Report No. N-69-28098, 360/ER-9967. Washington, DC, NASA, June 1969.
8. Provines W, Woessner W, Rahe A, Tredici T: The incidence of refractive anomalies in the USAF rated population. Aviat Space Environ Med 1983; 54: 622–7.
9. Miller R II, Woessner W, Dennis R, O'Neal M, Green R: Survey of spectacle wear and refractive error prevalence in USAF pilots and navigators. Optom Vis Sci 1990; 67(11): 833–9.
10. Baldwin J, Dennis R, Ivan D, et al: The 1995 Aircrew Operational Vision Survey: Results, Analysis, and Recommendations. Report No. SAM-AF-BR-1999-0003. Brooks Air Force Base, TX, USAF School of Aerospace Medicine, May 1999.
11. Provines W, Fischer J, Johnson L, Tredici T: USAF Undergraduate Pilot Training Pass/Fail Rate of Spectacled vs. Nonspectacled Student Pilots. Report No. USAFSAM-TR-85-50. Brooks Air Force Base, TX, USAF School of Aerospace Medicine, December, 1986.
12. Froom P, Ribak J, Burger A, Gross M: Visual acuity, corrective lenses and accidents in helicopter pilots. Aviat Space Environ Med 1987; 58: 252–3.
13. Still D, Temme L: Eyeglass use by U.S. Navy jet pilots: effects on night carrier landing performance. Aviat Space Environ Med 1992; 63: 252–3.
14. Tutt R, Ivan D: Aircrew spectacles: safety features and design considerations. Air Force recurring publication 91-1. Flying Saf 2003; 59: 4–7.
15. Wright S, Clark P, Tutt R, Stanek S, Gooch J: Corrective lens use and the interest in refractive surgery among USAF pilots. Aviat Space Environ Med 2008; 79: 107.