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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARD CONFERENCE PROCEEDINGS No.492

Ocular Hazards in Flight and Remedial Measures

(Les Risques Oculaires en Vol et les Moyens d'y Remédier)

NORTH ATLANTIC TREATY ORGANIZATION

Distribution and Availability on Back Cover

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Ocular Hazards in Flight and Remedial Measures

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Papers presented at the Aerospace Medical Panel Symposium held in London, United Kingdom, 22nd—26th October 1990.

North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

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Published May 1991

ISBN 92-835-0616-2

Printed by Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ

Preface

Vision is the aviator's most important sensory system and optimal visual performance must be maintained if operational effectiveness is not to be impaired. This Symposium considered the hazard situation, particularly directed energy, nuclear flash and solar radiation. Visual protection and correction was discussed, as was a number of clinical and theoretical aspects of the human visual system.

The Symposium was of interest to both clinicians and those interested in more technical aspects and equipment.

Préface

Pour l'aviateur, la vue est le système sensoriel le plus important et par conséquent, il est essentiel de maintenir les performances visuelles des pilotes au niveau optimal, afin d'empêcher toute diminution de leur efficacité opérationnelle. Ce Symposium a examiné les situations à haut risque, et en particulier l'énergie dirigée, le flash nucléaire et le rayonnement solaire. La protection et la correction de la vue sont parmi les sujets traités, ainsi [illegible] certain nombre d'aspects cliniques et théoriques du systèmes visuel humain.

Le Symposium a intéressé à la [illegible]iciens et les techniciens travaillant dans ce domaine.

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* Printed in classified publication CP-492 (Supplement).
† No paper available for publication.

* Printed in classified publication CP-492 (Supplement).

OPENING ADDRESS

by
Air Marshal N H Mills QHP, MB, BS, FFOM, D Av Med, RAF
Surgeon General, Defence Medical Services
Director General of Medical Services Royal Air Force

First of all, I should like to thank your Chairman, Mr Charles Bates, for his invitation to participate in this Opening Ceremony. Secondly, it gives me great pleasure, both as Surgeon General and as the Director General of Royal Air Force Medical Services, to welcome you all to the United Kingdom - to take part in this London Meeting of the Aerospace Medical Panel. This welcome goes to Mr Bates and his distinguished colleagues on the podium; and also to our distinguished friends and colleagues in the audience. With this greeting I should like, especially, to welcome those attending from outside the UK. You are all most welcome and we look forward to having you in our country during this week.

Since its formation in 1952, this Panel has covered much ground and has advanced scientific knowledge and understanding in the many areas of medicine related to aerospace. Recently, much work has been devoted to the protection of vision against natural and operational hazards occurring in flight.

The importance of the aviator's visual sensory system in the control of his aircraft and its weapons systems has long been recognized. It is, therefore, essential that he maintain optimal performance of his visual senses if impairment of his operational effectiveness is to be avoided.

In flight, various ocular hazards can degrade visual performance - notably, components of solar radiation and the radiation which emanates from lasers and nuclear explosions. The effects of these radiations may range from transitory visual impairment to permanent retinal damage and blindness.

However, there is now a better understanding of the mechanisms of ocular damage due to the effects of electromagnetic radiation in the visible, near ultra-violet and infra-red spectrum - and of its consequences. Active research and development has also been directed into the production of devices that protect both aircrew and ground personnel against the adverse effects of such solar and man-made radiations.

It is, therefore, timely that the Aerospace Medical Panel of AGARD should devote a Symposium to the topic of 'Ocular Hazards in Flight and Remedial Measures'. The Programme organized by the Panel provides a broad overview of the natural and man-made visual hazards, which may affect aviators. It also reviews methods of protection and the impact, which both radiation exposure and protective devices have on visual performance.

This information will be of undoubted value to those medical officers who have responsibility for the health and safety of aircrew; and it will assist them in educating flying and ground personnel about these matters. It should also help them to dispel the irrational fear, which some personnel hold, of being blinded by laser radiation.

The correction of refractive errors in aircrew by the use of corrective flying spectacles has long been a topic of aeromedical interest. The advent of contact lenses - over the past 10 years or so - and their use by flying personnel has solved some of the problems associated with spectacles, but has raised several others. A definitive report on the operational use of contact lenses is being prepared by this Panel's Working Group 16. However, this Symposium will provide an opportunity for specialists in this field to report to the aeromedical community on the use of contact lenses by aircrew and will also comment on other techniques, such as radial keratotomy - and the newer and more acceptable laser techniques - which can correct refractive errors.

These are but some of the subjects which will be covered in what promises to be a most fascinating programme; and there is much more besides. You have a busy and exciting programme and I do not wish to keep you from it any longer. I, therefore, wish you every success in the exchange of knowledge and information during your discussions at this Symposium and I trust you will all have a thoroughly enjoyable week together.

LASER EFFECTS UPON THE STRUCTURE AND FUNCTION OF THE EYE AS A FUNCTION OF DIFFERENT WAVELENGTHS

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Summary:

The word LASER is an acronym for " light amplification by stimulated emission of radiation".
A laser produces a narrow beam of monochromatic, coherent light in the visible, infrared or ultraviolet parts of the spectrum. The power in a continuous beam can range from a fraction of a milliwatt to around 20 kilowatts in commerical lasers, and up to more than a megawatt in special military lasers. Pulsed lasers can deliver much higher peak powers during a pulse, although the average power levels are comparable to those of continuous lasers.

The range of laser devices is broad. The laser medium, or material, emitting the laser beam, can be gas, liquid or solid. Lasers contain three key elements. One is the laser medium itself, which generates the light. A second is the power supply, which delivers energy to the laser medium in the form needed to excite it to emit light. The third is the optical cavity or resonator, which concentrates the light, mostly with the help of mirrors, to stimulate the emission of laser radiation.
Gas lasers use gas or a gas mixture as an active medium. The wavelengths range from ultraviolet to submillimetre. Gas lasers include Helium-Neon Laser, Argon-Ion Laser, Excimer-Laser and CO2 Laser.

The Helium-Neon Laser was one of the first continuous wave gas lasers. It is the most frequent and most economical laser producing light at 632.8 nm in the red part of the spectrum. The coherence of the beam is very good, but the output power is low. The active medium is a mixture of helium and neon. Helium-Neon Lasers have found a broad range of applications for instance as measurement instruments or in through-air-transmitted-communication systems. The beam is often used to draw a straight line for optical or electronic detection to aid in aligning or positioning. It is also used as a rotating sensor in laser " gyroscopes " for navigation. One of the principal commercial uses were in the Boing 757 and 767 aircraft.

The Argon Laser is the most important type of ion laser, which uses an ionized rare gas as active medium. The wavelengths are in the ultraviolet and visible wavelengths, and the output power ranges from about 100 watt in continuous wave to much more in pulsed delivery.
Major applications of the Argon Laser include pumping dye lasers to obtain adjustable continuous wave output and rapid computer printing. But the main application is in the medical field such as in dermatology, surgery and particularly ophthalmology.
(For example laser treatment of diabetic retinopathy and a retinal hole).

The Carbon Dioxide Laser is one of the most versatile types of lasers today. It emits infrared radiation between 9 nm and 11 nm (mainly at 10,6 nm) and can produce continuous output powers ranging from well under 1 W to 100 KWs. The active medium is a mixture of carbon dioxide, nitrogen and generally helium. The major applications are in the cutting and welding of metals and nonmetals. It can also be used as a laser radar or LIDAR (Light Detection and Ranging). This system generates 10 nm pulses and analyzes the returns. Returns from the atmosphere can be analyzed spectroscopically to determine concentrations of various substances in the atmosphere. For military applications, use of wavequide CO2 lasers as range finders is in the development and demonstration stages. The US laser monitor RAS (Remote Active Spectrometer) permits detection of chemically contaminated terrains.

The term excimer originated as a contraction of " exited dimer ", a description of a molecule consisting of two identical atoms which exists only in an exited state, examples include He2 and Xe2. Now it is used in a broader sense for any diatomic molecule in which the component atoms are bound in the exited state, but not in the ground state. The most important excimer molecules are rare gas halides. Excimer lasers emit powerful pulses (- 100 W) lasting nanoseconds or tenths of nanoseconds at wavelengths in or near the ultraviolet. Therefore the power output can be intensified to more than 10^{15} W/cm^2 by focusing the beam on a very small spot.

Most excimer lasers have been used in scientific research in a variety of fields sucn as pumping of tunable dye lasers, LIDAR systems and materials processing. In potential medical applications it is used to ablate surface tissure. In ophthalmology it became well known by refractive corneal surgery.

The neodymium laser is the most common member of a family generally grouped together as solid state lasers. Atoms present in impurity level concentrations in a crystalline or glass host material are excited optically by light from an external source, producing a population inversion in a rod of the laser material. The active medium in a neodymium laser is triply ionized neodymium, which is incorporated into a crystalline or glass structure. The most common host for neodymium lasers is yttrium aluminium garnet, a synthetic crystal with a garnetlike structure and the chemical formula $Y_3 Al_5 O_{12}$ that is known in the laser world by its acronym YAG. The wavelength of neodymium lasers normally is quoted as 1,06 nm. Output powers of continuous 1,06 nm YAG lasers range from a tenth of a watt to hundreds of watts. Peak power during a pulse can be much higher, from hundreds of kilowatts in a "normal" pulse to over a hundred megawatts in a Q-switched pulse.
Neodymium YAG lasers are finding increasing uses in medical treatment especially in ophthalmology and surgery.(For example a YAG laser iridectomy and a YAG laser capsulotomy of the posterior capsule) For military applications YAG lasers are often used as military range finders and target designators.
The best known solid state laser uses a rod of synthetic ruby as active medium. The ruby laser was the first laser demonstrated in pioneering experiments by Theodore H.Maiman. Today the ruby laser is often replaced by neodymium laser. But we can still find it used in military range finders and target designators.
The undesired effects of optical radiation on the eye:

The attendant hazards of laser operations vary greatly depending upon the exact type of laser and its application. The hazards also vary greatly, from the small lasers used for alignment to high powered pulsed neodymium lasers used as military range finders and target designators to still more powerful CO2 laser systems. The effects of optical radiation on the eye vary significantly with wavelength. The subject will be discussed in three sections. First the effects of radiation on the anterior portion of the eye will be considered. Second the effects of radiation upon the middle portion of the eye will be covered. The last and main emphasis will be on the posterior part of the eye, i.e. the retina, where the eye is particularly vulnerable to injury because of its imaging characteristics.

Injury to the anterior portion of the eye:
The anterior structures of the eye are the cornea, conjunctiva and sclera. The cornea is part of the optical pathway and as such must retain transparency. One of the more deleterious effects of injury to it is a loss of transparency. At very short wavelengths in the ultraviolet (180-315 nm) and long wavelengths in the infrared (1400-1000 nm) essentially all of the icident optical radiation is absorbed by the cornea. The cornea is exposed directly to the environment save for the thin lipid film - tear film, and therefore the surface corneal cells must necessarily have a high turnover rate. The corneal epithelium, the outermost living layer of the cornea upon which the tear layer flows, is almost completely renewed in a 4 to 7 day period. Hence, damage limited to this outer corneal layer is only temporary and seldom lasts more than one or two days. Unless deeper tissues of the cornea are also affected, surface epithelium injuries are rarely permanent injuries.

UV-B and UV-C (180-315 nm) radiation is absorbed in the cornea and sufficiently high doses will cause keratoconjunctivitis - that painful effect known to most as " snow blindness " or " welder's injury ". The initial effect of UV exposure is damage to or destruction of the epithelial cells. Injury to the epithelium is extremely painful as there are many pain fibers located among the cells of the epithelial layer.

After exposure, as in other photobiological responses, there is a characteristic latency period without subjective symptoms which varies inversely with the exposure dose. The period is generally between 6 and 12 hours, being longer for longer wavelengths. At exposures well above threshold this period may be less. The reddening of the conjunctiva is accompanied by lacrimation, photophobia (discomfort to light), blepharospasm (painful uncontrolled excessive blinking) and a sensation of " sand " in the eye. Corneal pain can be quite severe and the major treatment is the use of a corneal anaesthetic and ointment. But you should be careful with anaesthetic substances, they will reduce the pain but may induce corneal ulceration. Normal recovery of epithelium cells takes one to two days. Damage to the stroma and the other parts of the cornea are more of a problem. Damage to the stroma is usually followed by invasion of the entire cornea by blood vessels which turns the cornea opaque and when permanent it is difficult to treat except by grafting of a donor cornea.

IR-B and IR-C radiation is also absorbed in the cornea. Above 2000 nm absorption is very high, making the cornea very susceptible to far-infrared radiation heating. Radiation in the IR-C band can induce a burn on the cornea similar so that on the skin.

Injury to the middle portion of the eye:

The middle structures of the eye consist of the iris, lens, aqueous humor, vitreous body and ciliary body. The lens and aqueous humor are, as well as the cornea, part of the optical pathway and must retain transparence.

The lens, like the cornea, is an inhomogeneous material, yet it is in the visible range of the spectrum. This clarity is a result of a precise relation of the various minute, optically active constituents. Damage to the lens disturbs this relation and destructive interference of light rather than the normal constructive interference results with increased light scattering. The lens becomes milky. The parts of the cells around the lens developmental sutures are far away from the metabolizing part of the cells and are especially liable to injury.In distinction to the corneal epithelium the lens cells, especially those in the nucleus, have a very slow rate of repair. The lens has much the same sensitivity to ultraviolet as the cornea. However, the cornea is such an efficient filter for UV-C that little, if any UV-C light reaches the lens except at levels where the cornea is also injured. In the UV-A the cornea has substantial transmission while the lens has high absorption. Studies have shown that only the exposures in the UV-B appear to have a significant effect in causing lenticular opacities. The lenticular opacity may last only for a few days, then disappear if the exposure is sufficiently low. If the exposure is well above this level, the opacity which first appears at the anterior polar region, gradually progresses to the posterior cortex. Direct absorption of infrared radiation by the lens produces damage by direct degradation of the lens proteins.

For infrared wavelengths beyond 1.9 nm the absorbed energy of the cornea may be conducted to interior structures of the eye and elevate the temperature of that tissue as well as the cornea itself. Heating of the iris by absorption of the visible and near infrared radiation is considered to play a role in the development of opacities in the crystalline lens, at least for short exposure times. Ultraviolet light passing through the cornea could irritate the iris. For chronic exposures the possibility of developing melanoma exists.

As the threshold for injury of the iris is very high compared to the other anterior structures, it is not often injured. Inflammation of the iris by overheating can cause adhesions to either the cornea of the lens. These adhesions can be very painful and may also give rise to unwanted pathological changes in either the lens or the cornea. Adhesions can cause increasing intraocular pressure which can induce a reduced visual field up to blindness later on. The aqueous humor, as it name implies, is essentially water, hence one cannot speak of " injury " to the aqueous. The aqueous as well as the cornea serves as a heat-absorbing waterfilter for the lens, protecting it from IR-B and IR-C thermal radiation. Of course in this role any significant elevation of the temperature of the aqueous will be transferred to the lens by conduction. The vitreous body and ciliary body are normally not affected by laser radiation. The possible damage could rise from high temperatures emitted by IR-C radiation inducing protein denaturation.

Injury to the poserior portion of the eye:

The posterior portion of the eye consists out of the retina, retinal pigment epithelium and choroid. The retina is most vulnerable to visible light (400 - 700 nm) and near infrared radiation (700 - 1400 nm). Both are sharply focused onto the retina. When an object is viewed directly, the light forms an image in the fovea, the center of the macula. The typical result of a retinal injury is a blind spot or scotoma within the irradiated area. The optical properties of the eye also play an important role in determining retinal injury. Such factors as pupil size, spectral absorption and scattering by the cornea, aqueous, lens and vitreous, as well as the absorption and scattering in the various retinal layers will now be described in order to help to get a better idea of the possible lesions.

The limiting aperture of the eye determines the amount of radiant energy entering the eye and therefore reaching the retina. The energy transmitted is proportional to the area of the pupil. There is a big difference between the pupil size of a normal dark-adapted eye and that of an outdoor daylight-adapted eye. The constricted pupil normally accepts onesictecnth of the light admitted by a dark-adapted eye. It is important to remember that pupil size for a given environment varies with age, emotional state, and other factors - notably the use of some medications which create abnormally large pupil sizes. Also direction of the rays is of importance: The central area of the retina is more effective in producing the same pupil constriction than peripheral parts. The different regions of the retina play different roles in vision due to their different power of resolution.

Therefore the significance of functional loss of all or part of any one of these regions varies. The greatest visual acuity is localized in the fovea loss of this retinal area dramatically reduces vision. A central scotoma would occur if an individual were looking directly at the source of the incident laser radiation during exposure. The size of the scotoma would depend upon whether the injury was near to or far above the threshold irradiance and the angular extent of the source of radiation. A scotoma due to a lesion in the peripheral retina may even go unnoticed.

As pointed out previously the visible and near infrared radiation is transmitted through the ocular media and is absorbed principally in the retina. However, it must first pass through the neutral layers of the retina before reaching the retinal pigmented epithelium and chorioid. The retinal pigmented epithelium absorbs about 50 % of the light and is optically the most dense absorbent layer. As the absorption takes place in a highly concentrated layer of melanin granules, the greatest temperature rise exists in this layer. The mechanism of injury is considered to be largely thermal for accidental exposures from CW lasers or the sun for durations on the order of 0,1 s to 10 s or from exposures from long-pulsed lasers or flashlamps on the order of 1 ms to 10 ms. Since injury appears to result principally from protein denaturation and enzyme inactivation, the variation of temperature with time of the retinal tissue during and following the insult must be considered.

Thermal injury is a rate process, therefore no single critical temperature exists above which injury will take place independent of exposure duration. For narrow ranges of exposure duration, a critical temperature should predict injury thresholds if photochemical effects are not present. Shorter exposures require greater temperatur elevations for the same degress of retinal injury - at least for exposure durations greater than 1 ms.

It seems that life - long exposure to light plays a role in retinal aging. Certain age related retinal changes may be light initiated. There is a strong similarity between histological and ultrastructural changes in aged retina and those in retina experimentally exposed to intense light sources. Studies were conducted during and following World War II of the effects of prolonged exposures of individuals to bright ourdoor environments upon night vision and retinal sensitivity. Lifeguards exposed to the high luminance environment encountered at the seashore have shown both a short term depression in photoptic sensitivity and a marked long term loss of scotopical (night) vision.

Prevention of laser-induced injuries:

The best protection of the eye is not to look at the light. There are also laser protective eyewear, i.e. goggles, spectacles and standard spectacles with special lenses to prevent ocular injury from laser radiation. Narrow band-filter eyewear will reject specific laser wavelengths while transmitting light required for vision Sensor activated high speed shutters or photochemically reacting absorbing protection glasses also might be helpful.
The eyewear protects the eye, but also may reduce vision, the visual field and military performance under low light conditions.

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EFFETS OCULAIRES DU FLASH NUCLEAIRE ET EVALUATION DE L'EBLOUISSEMENT ASSOCIE

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RESUME

Après l'exposé d'une définition de l'éblouissement et des mécanismes responsables, ce travail propose une analyse statistique de données expérimentales permettant de définir un estimateur précis du temps de récupération d'une acuité visuelle de 3/10 pour une luminance de tâche donnée après exposition à un flux lumineux intense de lumière non cohérente, d'un sujet humain adulte adapté à l'obscurité.

I INTRODUCTION

Les effets lumino-thermiques des armes nucléaires sur la fonction visuelle sont de deux types :

- l'éblouissement : . à court terme, c'est à dire de l'ordre de la minute,
  . à long terme avec atteinte réversible de la fonction visuelle,
- les brûlures rétiniennes.

Les résultats des recherches opérationnelles sont sensiblement les mêmes dans les différentes armées du monde : il s'avère que l'éblouissement et à fortiori la brûlure rétinienne définitive peuvent compromettre de manière inacceptable l'action du personnel engagé dans une mission décisive.

Après une analyse des différents paramètres en cause et une revue de la littérature internationale portant sur l'éblouissement expérimental, il est proposé une comparaison des temps de restauration permettant de retrouver une acuité visuelle compatible avec une tache visuelle définie, en fonction de l'énergie intégrée du stimulus au niveau de la rétine.

L'analyse des travaux expérimentaux est rendue difficile par deux facteurs :

- la diversité des conditions d'éblouissement (nature de la source, angle sous lequel est vue la source, définition de la tâche visuelle),
- l'utilisation d'unité des mesures différentes.

II LE FLASH NUCLEAIRE

Deux concepts sont importants en unités radiométriques :

- la puissance ou flux, c'est à dire l'énergie délivrée par unité de temps en watt ou $cal.s^{-1}$ et l'irradiance, ou énergie par unité de temps et de surface en watt (ou $cal.s^{-1}).cm^{-2}$,
- l'énergie totale en joules ou calories, et l'exposition, ou énergie totale par unité de surface en J (ou $cal).cm^{-2}$.

Dans le cas des armes nucléaires, l'énergie délivrée est considérable mais son évolution temporelle va dépendre de la puissance de l'arme. Pour des engins inférieurs à 100 KT, la plus grande partie de l'énergie est délivrée en moins de 150 ms donc en deçà du délai du reflex palpébral (fixé à 150 ms en France). Pour des énergies bien supérieures, le réflex palpébral et le détournement de la tête vont conduire à des phénomènes plus complexes.

L'atteinte de la fonction visuelle va dépendre :

- de la température de couleur dont l'influence sera d'autant plus grande que l'émission apparaît dans une bande de longueur d'onde où la sensibilité de la rétine est maximale (555 nm).

- de l'éclairement intégré sur la rétine en $watt.cm^{-2}$ que l'on peut également exprimer en troland.s, unité physiologique qui exprime le flux lumineux total passant à travers une pupille dont la surface est donnée en mm^2 : 1 troland = mm^2 x Luminance en $candéla.m^{-2}$.

- de la visibilité qui joue comme un facteur d'atténuation et de diffusion. Si le flux est direct, non diffusé, il s'accompagne de la formation d'une image et l'atteinte de la fonction visuelle va dépendre de sa localisation sur la rétine.

III L'EBLOUISSEMENT

C'est une perte temporaire de la fonction visuelle chez un sujet soumis à une énergie lumineuse supérieure à celle de son niveau d'adaptation. Il se traduit par des phénomènes électrophysiologiques et biochimiques au niveau de la rétine et dans une moindre mesure au niveau des voies, relais et aires de projection et d'associations visuelles.

En pratique, la mesure quantitative de l'éblouissement est le temps nécessaire à la récupération d'une acuité visuelle (AV) partielle déterminée ou totale, ou encore d'une aptitude à réaliser une épreuve, c'est à dire la reconnaissance d'un symbole. La définition de l'épreuve, ou tâche visuelle, ne peut donc être séparée de la définition de l'éblouissement. En règle générale, le temps de récupération a été étudié :

- pour des tests non mémorisables comme le retour à une AV de 3/10 nécessaire pour la lecture d'une lettre ou d'un anneau de Landholt,

- pour des test mémorisables comme le retour à une AV permettant la lecture d'un cadran ou d'un tableau de bord.

De nombreux paramètres vont influer sur la mesure de l'éblouissement.

III-1 Paramètres permettant de définir l'éblouissement

III-1-1 L'énergie radiante du stimulus.

C'est le facteur essentiel. En règle générale, le temps de récupération (TR) augmente en fonction de l'énergie lumineuse intégrée. On peut exprimer TR (en secondes) par :

$$TR \simeq K_1 \text{ Log } E + a$$

où K_1 est un facteur dépendant de la luminance de l'objet visualisé. Cette fonction n'est approximable que pour E compris entre 2.10^5 et 5.10^8 troland.s.

III-1-2 Angle (α) sous lequel est vu le stimulus et localisation de l'image rétinienne.

Le TR est d'autant plus long que l'image rétinienne, fonction de α, est grande. Très approximativement :

$$\text{Log } TR \simeq K_2 \text{ Log } (\alpha) + b$$

En réalité des études expérimentales ont montré pour $\alpha < 2°$, le TR est sensible à de faibles variations de la luminance de la tâche alors que pour $2° < \alpha < 15°$, TR reste quasi constant avec la luminance.

L'AV diminue très vite de la fovéola à la périfovéa. A 10° du centre elle n'est plus que de 4/10 et 1/10 à 30°. Si l'image du stimulus couvre 2,5° sur la fovéa, l'AV est réduite à 60% de sa valeur. Selon la localisation de l'image du stimulus éblouissant et celle de l'objet visualisé, plusieurs cas se présentent :

- L'image du stimulus éblouissant se forme sur la fovéa :

. si la détection de l'objet visualisé est sur la fovéa, le TR est le plus long car la lecture se forme sur la post-image (perception d'une image fictive).

. si la détection est péri-vovéale, le TR reste long car la sensibilité péri-fovéale de la rétine est plus faible.

- L'image du stimulus éblouissant ne se forme pas sur la fovéa. Pour un objet détecté sur la fovéa, le TR est d'autant plus court que a distance séparant les deux images est plus grande. Si l'image du stimulus et de l'objet se superposent, le temps de récupération reste long.

III-1-3 Niveau d'adaptation avant la stimulation et diamètre pupillaire.

Bien qu'étroitement liées, il n'y a pas identité entre les deux. L'adaptation est une variation de la sensibilité rétinienne conditionnant l'ouverture de la pupille. En pratique, le niveau d'adaptation en lui-même n'a d'effets que sur la lisibilité de la tâche visuelle ; le TR sera surtout fonction du rapport existant entre la luminance de l'objet visualisé et l'éclairement définissant le niveau d'adaptation.

- En vision photopique (luminance du champ visuel de 318 $cd.m^{-2}$).
  D = 2-3 mm.
- En vision scotopique (luminance du champ visuel de 0,318 $cd.m^{-2}$).
  D = 7-8 mm.

Ceci donne un rapport de 5,5 à 1 dans l'énergie intégrée au niveau de la rétine. De plus, le diamètre pupillaire est une fonction du temps : Si la pupille réagit en 1 ms, elle n'atteint sa valeur d'équilibre avec le milieu d'adaptation que plus tard (2 s).

Adaptation et diamètre de la pupille influencent le plutôt le TR durant la reconnaissance de la tâche visuelle ; sur le plan pratique, un sujet adapté à la vision photopique aura un TR plus long qu'un sujet adapté à la vision scotopique pour déchiffrer une tâche sous luminance faible.

III-1-4 Luminance et nature de la tâche visuelle.

Dans la gamme d'énergie de 10^5 à 5.10^8 tr.s, le TR est d'autant plus long que la luminance (L) de l'objet visualisé est plus faible selon l'expression :

$$\text{Log } (TR) \simeq K_4 \text{ Log } L + c$$

et ceci pour un sujet adapté en vision scotopique. c varie selon la dimension de l'image du stimulus (fonction de α). K_4 est voisin de 0,8. L'effet de la luminance est d'autant plus grand que la luminance est faible (α<1 lx) ; pour des luminances élevées, l'influence sur le TR est beaucoup moins importante.

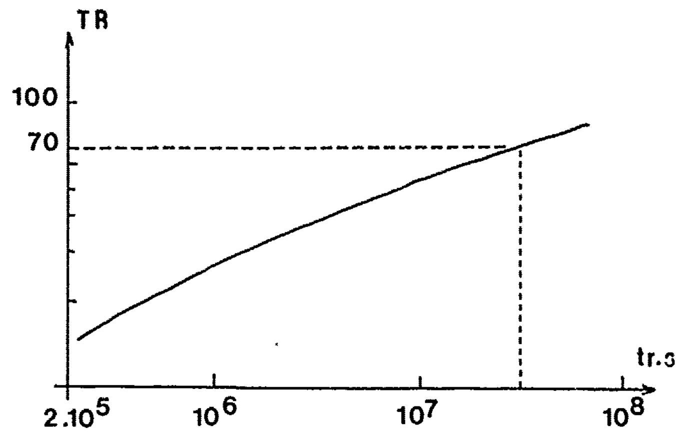

Fig 1

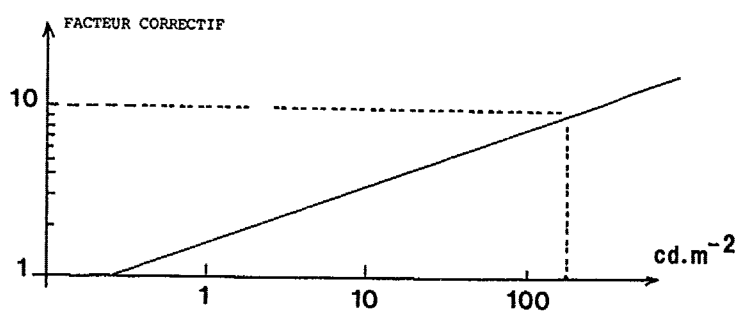

Fig 2

Fig. 1: Temps statistique nécessaire au retour d'une acuité visuelle de 3/10, d'un sujet normal, adulte, adapté à l'obscurité (en secondes). Luminance de la tâche: 0,3 $cd.m^{-2}$

Fig. 2: Facteur correctif du TR en fonction de la luminance de la tâche.
Exemple: pour 3.10^7 tr.s et pour une tâche de 0,3 $cd.m^{-2}$, TR = 70s. Pour une tâche de 200 $cd.m^{-2}$, le facteur correctif est 10, ce qui ramène TR à 70:10 = 7s.

Le TR est fonction des dimensions de l'objet visualisé et de sa forme. Il diminue lorsque l'angle sous lequel est vu l'objet augmente.

Pour des tests non mémorisables (lettres, anneaux) le TR est en général plus long que pour lire les indications d'un tableau de bord.

A énergie égale le TR sera plus court si le spectre d'émission est calé dans une bande de longueur d'onde où la sensibilité de l'oeil est maximale.

III-2 Etude statistique des résultats.

L'analyse de 350 données expérimentales, obtenues tant sur le terrain qu'au laboratoire, a permi de définir les TR compte tenu de l'exposition et des paramètres physiques de la tâche visuelle. Deux paramètres ont été retenus :

- L'éclairement intégré sur la rétine lors de l'exposition au flash (recalculées en troland.s),

- La luminance de la tâche (en $cd.m^{-2}$).

L'ensemble des résultats porte sur des tests mémorisables (retour à une AV de 3/10) et des tests mémorisables (lecture d'un cadran).

On peut ainsi proposer un estimateur assez simple d'emploi, susceptible de donner une estimation du TR, et qui est un temps statistique nécessaire au retour d'une activité visuelle de 3/10 d'un adulte normal, adapté à l'obscurité (figures 1 et 2).

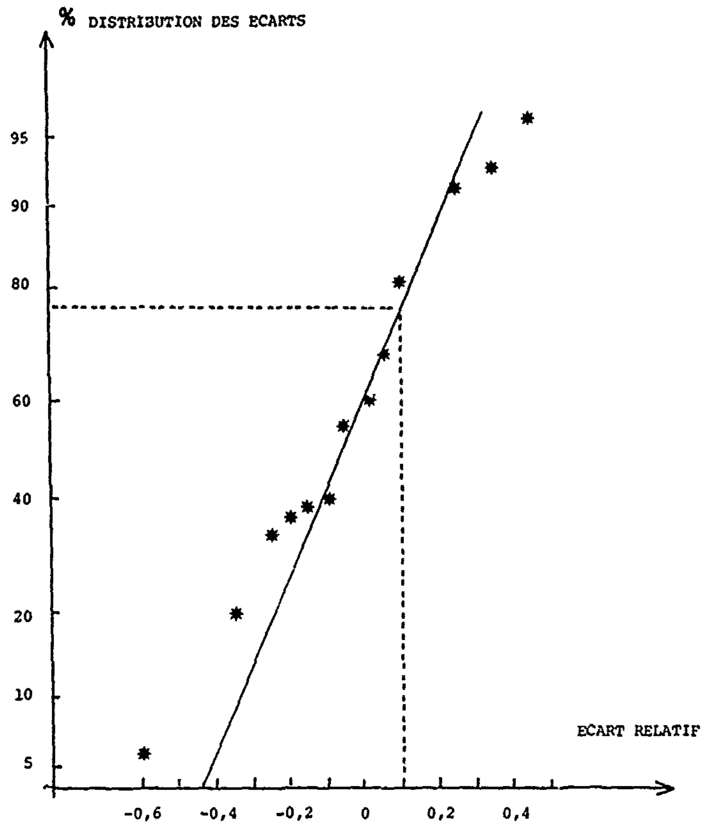

Fig. 3

Fig. 3: Distribution des écarts entre le TR mesuré (✱) et les TR estimés par les abaques des figures 1 et 2 pour les mêmes conditions expérimentales. Cette distribution concerne 350 données expérimentales.

En outre, dans 90% des 350 cas retenus, la prévision mathématique donne le temps de récupération à moins de 40% près, ce qui est meilleur que l'incertitude dont est entachée une bonne part des résultats expérimentaux (figure 3).

IV LES LESIONS IRREVERSIBLES

Ce sont les brûlures. On s'est surtout intéressé à la recherche des valeurs limites d'exposition, à partir d'études expérimentales sur le terrain ou en laboratoire, mais aussi de données en ophtalmologie clinique.

Ces valeurs limites sont surtout fonction de l'énergie intégrée (exposition) mais aussi du paramètre temps à travers l'irradiance.

A titre d'exemple, on peut citer trois travaux :

- Demott et Davis ont montré chez le lapin, le cobaye, le chien et le singe qu'aucune lésion n'apparaissait pour des irradiances de 0,7 $cal.cm^{-2}.s^{-1}$, quel que soit le temps d'exposition. Pour ces auteurs, avec une irradiance de 2 $cal.cm^{-2}.s^{-1}$, le seuil de lésion est de 1 $cal.cm^{-2}$.

- Pour le document allemand FINABEL, les distances de sécurité ont été proposées sur une base de 0,1 $J.cm^{-2}$ et de 0,5 $J.cm^{-2}$ intégrés à la rétine sur les 170 ms retenus pour le réflexe palpébral.

- Le rapport US, DASIAC AD 765 334, propose un seuil de lésion pour une élévation de température de 10° à 30°C à la surface de l'épithélium pigmentaire.

Il est raisonnable d'adopter pour l'instant des valeurs de seuil correspondant à une exposition de 0,1 $J.cm^{-2}$.

Mais ce seuil va varier avec la dimension et la position de l'image sur la rétine :

- Une lésion intéressant l'aire comprise entre la macula et la papille (émergence des fibres) a des conséquences gravissimes ;

- Une atteinte para-fovéale ou en périphérie de la rétine entrainera toujours un éblouissement plus ou moins prolongé, mais dans ce dernier cas, la lésion peut n'être qu'une découverte à l'occasion d'un examen du champ visuel.

En règle générale, une illumination avec lésion définitive entraine souvent la perte de la fonction visuelle, plus ou moins marquée, une sensation douloureuse plus ou moins importante apparaissant immédiatement après l'exposition et pouvant se prolonger.

V LES MOYENS DE PROTECTION

Ce sont essentiellement les filtres passifs ou actifs.

V-1 Les filtres passifs

- Les filtres de type interférentiel à large bande. Leur transmission maximale est de l'ordre de 0,1 à 10% dans le visible, mais leur bande passante est dans le jaune. Leur emploi n'a donc pas été retenu par l'Armée de l'Air française. Par contre à 1060 nm la D.O. est de 3 à 4.

V-2 Les filtres actifs

Les spécifications idéales d'un filtre actif sont les suivantes :

. D.O. à la fermeture 4,

. Temps de réponse pour passer de :
l'état ouvert à l'état fermé : 100 µs pour atteindre une D.O. = 3,
l'état fermé à l'état ouvert : 0,5 à 5 s.

. A l'ouverture transmission de 35 à 50%,
bonne vision des couleurs,
champ visuel latéral minimum de ± 60°.

. Réalisable sous forme de visière-plan.

Parmi les différentes solutions expérimentées, on peut citer :

- Les substances photochromes activables et réversibles présentant un spectre d'absorption dans le visible important et une cinétique de réaction rapide mais nécessitant une énergie de mise en oeuvre non miniaturisable et incompatible avec un équipement personnel (1500 V).

- Les céramiques PLZT (plomb-lanthane-zirconium-titane), déclenchable par photodétecteur. Leur transmission à l'ouverture est de 15 à 20% et de 0,01% entre 480 et 680 nm. Leur temps de réponse est de 30 à 100 µs selon la transmission. Non retenus car trop coûteux actuellement.

ULTRAVIOLET RADIATION EFFECTS ON THE CORNEAL EPITHELIUM

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Abstract Introduction

Since military troops are involved in extensive outdoor activities with chronic exposure to solar radiation, and since ultraviolet radiation (UVR) lasers may play a role in the future military environment, a thorough understanding of UVR damage mechanisms would be crucial to the development of intervention and treatment modalities. The present research was directed at quantifying possible alterations in corneal epithelial metabolic activity secondary to in vivo exposure to UVR in the rabbit.

Abstract Methods and Results

A 5,000 Watt Hg-Xe arc lamp served as the UVR source. The radiant exposures were kept constant at 0.05 $J \cdot cm^{-2}$ for all UVR wavelengths used (290, 300, 310, and 360 nm). Wavelength isolation was accomplished with a double monochromator providing a 6 nm full bandpass. The four experimental wavelengths were chosen based on an interest in maintaining an environmental relevance, since 290 nm UVR and above can be found at the earth's surface. Micropolarographic measurement of corneal oxygen uptake rates served as an in vivo index of UVR-induced effects on oxidative metabolism.

Microfluorometric analyses of key epithelial energy metabolites (glucose, glycogen, ATP, and PCr) were used as an in vitro index of UVR-induced effects on overall metabolic activity. A paired difference analysis of the oxygen uptake rate data demonstrated a decrease in relative corneal oxidative metabolic activity that was wavelength-dependent. These same experimental UVR exposure conditions served to significantly increase epithelial glucose and glycogen concentrations. Although the epithelial ATP concentrations were unchanged, the epithelial PCr concentrations (a high energy phosphate bond reservoir) decreased as a result of UVR exposure.

Abstract Conclusions

These data demonstrate a decrease in corneal epithelial oxidative metabolic activity as a result of UVR exposure, and infer an adverse effect on glycolytic metabolism, as well. It is suggested that immediate UVR-induced metabolic inhibitory effects can be responsible for the pattern of epithelial cell loss seen in photokeratitis.

INTRODUCTION

Ultraviolet radiation (UVR) has been implicated within public health arenas as a potential stimulus for degenerative ocular changes since the time of the ancient Greeks.[1] Recent speculation concerning changes in the nature of the atmospheric ozone layer has led to increased interest in adverse effects of UVR exposure. The advent of UVR lasers have further spurred research interest concerning the determination of possible mechanisms of action, since the development of a full spectrum of applications is dependent upon a thorough understanding of operant mechanisms.

The ideal tissue for investigating the in vivo effects of UVR is the corneal epithelium. As the most anterior tissue layer of the eye, the corneal epithelium is subject to a direct interaction with incident radiation. The tissue is uncomplicated by spurious absorbers, thermal effects, or pigmentary photochemistry. Additionally, its avascularity and accessability enable response gathering uninfluenced by circulatory system factors remotely external to the tissue. Finally, the corneal epithelium is exposed to UVR on a daily basis, so exposure studies are not subjecting the tissue to a completely unnatural condition.

Many investigations into the effects of UVR on the corneal epithelium have concentrated on morphological evaluations utilizing the biomicroscope, the light microscope, and/or the electron microscope (Verhoeff and Bell, 1916; Cogan and Kinsey, 1946; Pitts and Tredici, 1971; Ringvold, 1980 and 1983). Such studies have provided detailed information concerning the delayed structural changes characteristic of UVR damage that occur 4 to 12 hours after exposure. As a result of this histological detection delay, information concerning either immediate or functional effects of UVR cannot be probed by such methods.

Millodot and Earlam (1984), seeking to evaluate this damage-delay phenomenon, revealed the presence of a period of decreased corneal sensitivity immediately following exposure to UVR. Their finding appears to signify an immediate effect of UVR upon the sensory neurons subserving the corneal epithelium. If such is the case, and knowing that these axons appear deep within the basal cell layer of the

[1] Xenophan's treatise "Anabasis" discusses the condition of "snowblindness."

corneal epithelium and within the anterior stroma, it would be reasonable to assume that there might also be an immediate effect of UVR on the corneal epithelium itself. Therefore, the purpose of this study was to evaluate the possible immediate effect of exposure to UVR on the metabolism of the corneal epithelium in the rabbit.

Selection of the exposure wavelengths (290, 300, 310, and 360 nm) was based on an interest in maintaining an environmental relevance. An additional factor was the intention of creating a distinctive span of effects by maintaining a constant level of radiant exposure at 0.05 J·cm^{-2} with varied wavelength challenges. Measurement of the corneal oxygen uptake rate served as an *in vivo* assessment of epithelial metabolic activity, while microfluorometric metabolite analyses served as an *in vitro* index of epithelial metabolic activity.

MATERIALS AND METHODS

- adult, pigmented rabbits (2-2.5 kg)
- anesthesia: Ketalar (10 mg/kg) and Rompun (5 mg/kg)
- source calibration and radiometric quantification duplicated procedures described by Pitts et al (1977) [for a complete description, see Lattimore[a,b] (1989)]

- *in vivo* experiments allowed return of rabbits to vivarium for non-ocular research
  - micropolarographic system duplicated that of Benjamin and Hill (1986) [for a complete description, see Lattimore[a] (1989)]
  - five baseline oxygen uptake recordings from each eye
  - animals with excessive baseline variation rejected
  - predetermined radiant exposure
  - recordings again made two minutes after UVR exposure discontinued
  - paired-difference analysis

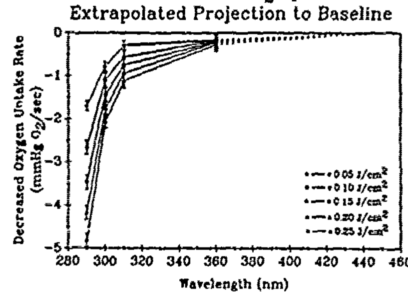
- *in vitro* experiments necessitated sacrifice by cervical dislocation 2 minutes after UVR exposure [for a complete description, see Lattimore[b] (1989)]
  - eyes immediately removed and immersed in liquid nitrogen to prevent significant change in metabolite levels
  - control animals: mock-exposure, identical procedures
  - -80° C freezer storage of eyes
  - cornea removed from globe, -30° C Wedeen cryostat
  - corneal halves mounted on a sectioning button
  - cryostatic microtome sectioning (20 micrometres (μm))
  - freeze-dried @ -20 C° for 24 hours
  - when samples needed, thawed under vacuum for 1 hour to prevent condensation-stimulated enzyme action
  - 3X binocular dissecting scope used to isolate epithelium
  - tissue size determined by dry weight, quartz fiber fishpole balance (μg sensitivity)
  - placed in oil well rack for specific metabolite assay
  - utilized microfluorometric techniques established by Lowry and Passonneau, 1972

RESULTS

Introductory data (Figures 1 and 2) have been previously published (Lattimore, 1989[a]; Lattimore, 1989[b]), and are currently used as a basis for detailed analyses. Figures 3 and 4 isolate oxygen uptake as a function of corneal epithelial PCr, ATP, glucose, and glycogen concentrations. In the current unit format these data are not easily compared in any fashion other than in a general graphical relationship. Within this general framework there is very close correlation, implying a direct relationship between UVR-altered oxygen uptake rate and certain metabolite changes. ATP was found to be stable across all changes in oxygen uptake associated with UVR exposure ($r = 0.07$). Glucose and glycogen were found to accumulate as a function of UVR-altered oxygen uptake ($r = 0.97$ and 0.98, respectively); PCr depletion also correlated well with changes in UVR-altered oxygen uptake rates ($r = 0.84$).

Figure 1

UVR–Altered Corneal O_2 Uptake Rate·
Extrapolated Projection to Baseline

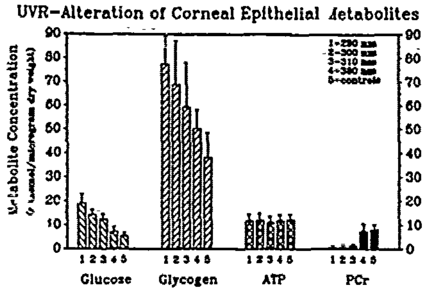


Caption for Figure 1

By plotting the UVR-altered corneal oxygen uptake rate data as a function of wavelength, and by making separate data-sets for each radiant exposure, a "family" of plots is obtained. A two-way analysis of variance demonstrated an overall significant between-groups difference ($p < 0.0001$), as well as revealed an interactive effect between wavelength and dose ($p < 0.005$). Unexposed eyes exhibited no significant change in corneal oxygen uptake rates over the course of the experiment.

Figure 2

UVR-Alteration of Corneal Epithelial Metabolites

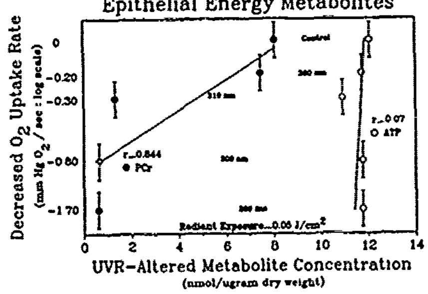


Caption for Figure 2

Figure 2 provides a bar-chart illustration of various epithelial metabolite concentrations as a function of the wavelength of UVR exposure. An analysis of variance of the data demonstrated a highly significant overall, between groups effect ($p<0.0001$) for glucose, glycogen, and PCr. An analysis of variance of ATP data failed to demonstrate a significant effect ($p>0.65$), illustrating an apparent ATP-sparing process.

Figure 3

Corneal O_2 Uptake vs Epithelial Energy Metabolites

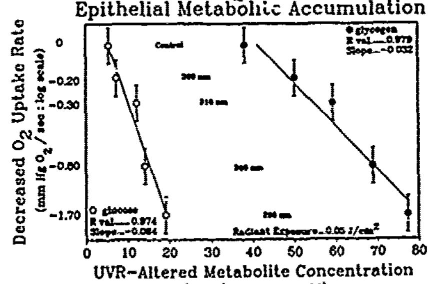


Caption for Figure 3

Plotted decreases in the oxygen uptake rate as a function of PCr and ATP, illustrate ATP-sparing at the apparent expense of PCr.

Figure 4

Corneal O_2 Uptake vs Epithelial Metabolic Accumulation



Plotted decreases in the oxygen uptake rate correlate highly with accumulations of glucose and glycogen. However, plotted units are not directly mathematically comparable. Therefore, the established relationship between oxygen and glucose should, for the moment, be considered a qualitative relationship only.

DISCUSSION

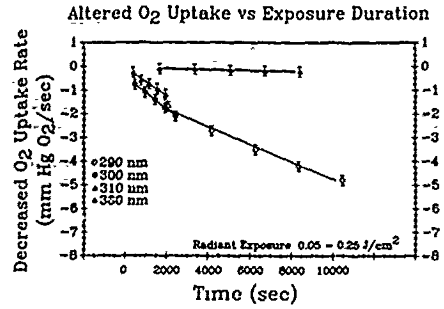
The corneal epithelium is known to conduct both aerobic and anaerobic metabolic activity concurrently (Kinoshita and Masurat, 1959). According to some estimates, the rabbit corneal epithelium routinely consumes up to 85% of available glucose in anaerobic channels, with the remaining 15% used via aerobic channels (Riley, 1969). When anaerobic conditions are artificially imposed upon a cornea (i.e., by the application of a thick contact lens), the tissue response has been portrayed to be increased anaerobic activity, inferred by the depletion of epithelial glycogen stores (Uniacke and Hill, 1972). Yet, under the UVR exposure conditions of this experiment, decreased oxygen utilization was evidenced with a contradictory accumulation of both glucose and glycogen, rather than the expected depletion. This paradox led to the examination of oxygen uptake changes as a dependent variable of key metabolites.

The results indicate: a decrease in oxygen consumption, an apparent decrease in glucose utilization, a stabilization of ATP, and a decrement in PCr. The manifested close relationship between the research variables point toward an alteration of oxidative or mitochondrial activity resulting from UVR exposure. Additionally, paradoxical glucose and glycogen accumulations suggest a secondary underlying effect on the anaerobic or glycolytic chain. A global enzyme inactivation can be excluded because glycogen and ATP storing are enzymatically mediated. Therefore, it can be concluded that observed UVR effects are the result of more than one damage mechanism. However, this close correlation stems from a superficial view; translation of oxygen data to units more directly comparable could provide a greater insight into operant mechanisms of UVR damage.

By plotting oxygen uptake changes as a function of exposure duration (Figure 5), one can examine slope differences in wavelength effects. The 360 nm data possess a distinctly different slope than the other wavelengths. Since 360 nm oxygen and PCr levels are not significantly affected by UVR exposure, it is likely that 360 nm effects of UVR are not centered upon the mitochondria, but elsewhere in the metabolic chain. This analysis, however, doesn't differentiate relative contributions of mitochondrial and anaerobic effects secondary to 290, 300, and 310 nm exposures. In an attempt to accomplish such a differentiation, oxygen data was mathematically integrated over the 0.05 J/cm^2 radiant exposure period. It was not necessary to do this for metabolite data, because metabolite data represent a natural integration over the total exposure.

Figure 5

Altered O_2 Uptake vs Exposure Duration

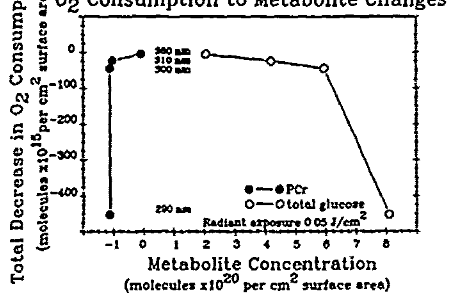


Caption for Figure 5

Comparison of the oxygen-exposure time slope data highlight 360 nm effects to be independent of other wavelength mechanisms of action. The combined absence of oxygen effects accompanied by glucose accumulation suggest the presence of a damage mechanism isolated within the anaerobic stages of metabolism.

Figure 6

Direct Comparison of UVR-Altered O_2 Consumption to Metabolite Changes



Caption for Figure 6

Total glucose and PCr concentrations for 290 nm exposures are clearly outside any potential linear relationship that might be suggested by 300, 310, and 360 nm data. This dramatic dropoff in PCr, combined with the nonlinear accumulation of glucose found in 290 nm exposures suggest the presence of a damage mechanism isolated at the level of mitochondrial function.

Since oxygen data are theoretically translatable from mm Hg O_2/sec to ul/cm^2, and metabolite data can be translated from nmol/ug to nmol/cm^2, a directly comparable unit correlation may be obtained. This method of data presentation (Figure 6) highlights the relative relationships between mitochondrial and anaerobic metabolism, with UVR wavelength. Short wavelength UVR (i.e., 290 nm and possibly shorter) are shown to possess predominantly an adverse mitochondrial effect on the corneal epithelium, since PCr dramatically falls off compared to the other wavelength exposures, and total glucose accumulations are much less than a standard, linear model would predict. As the exposure wavelength increases, total glucose accumulation and PCr depletion conform to a linear representation when compared to equivalent oxygen decrements. Therefore, it can be concluded that observed UVR effects on the corneal epithelium are the result of more than one damage mechanism. UVR exposures at or near 360 nm will produce effects predominantly by way of disruption of anaerobic/glycolytic metabolic pathways. UVR exposures at and possibly below 290 nm will produce effects predominantly by way of disruption of aerobic/mitochondrial metabolic pathways. UVR exposures at intermediate wavelengths will produce compound effects on the corneal epithelium involving both damage mechanisms.

SUMMARY

Corneal epithelial metabolism is affected adversely by a dual mechanism of UVR damage. This duality differentially presents itself dependent upon exposure wavelength. While considerable overlap is possible, clearly short wavelength UVR is predominantly toxic to the mitochondrial system, while longer wavelength UVR predominantly affects the anaerobic metabolic pathways. Dual damage mechanisms, with overlapping action spectra could complicate the development of intervention and treatment modalities. Specific enzymatic analyses will be necessary to fully elicit wavelength specificities and potential treatment options.

1. The views of the author do not purport to reflect the position of the Department of the Army or the Department of Defense.

2. Citation of trade names does not constitute official Department of the Army endorsement or approval of the use of such commercial items.

3. All procedures involving animal research adhered to guidelines established by the National Research Council Committee on Animal Research.

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EYE DAMAGE INDUCED BY SOLAR RADIATION

by

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The visible spectrum of the sunlight is but a small fraction of the huge spectrum of electromagnetic waves called light which is vital for the existence of life.

Part of the population increasingly exposed to solar radiation for reasons of profession are the flying personnel. The question concerning noxious effects of solar radiation and especially high altitude radiation on the eye deserves differentiated consideration. The predominant portion of radiation arriving on the earth stems from the sun, a smaller percentage reaches us from other radiating sources. Upon entry into the atmosphere the various layers cause scattering absorption, emission and radiation transmission dependent upon wavelength.

What types of rays and radiation energies are prevalent in cruise altitudes of 10 km? Considering effects and occurrence two types of rays are to be found, i.e. ionizing and non-ionizing rays. Both types of rays are subjected to different attenuation during penetration of the atmosphere.

Ionizing radiation:

Typical representatives of this type of rays are alpha-, beta-, gamma-, and neutron rays as well as short wave UV-rays (< 100 nm). These rays are chiefly triggered off by protons from the sun which induce this radiation because of interactions of atoms and molecules of the various atmospheric layers.

The primary cosmic radiation is under the influence of the earth's magnetic field. For this reason and dependent upon the geographic latitude man is exposed to varying radiation effects.

When describing the effects of ionizing radiation (>13.5 eV) on biologic material one has to differentiate between the effects on molecular, cellular, and organic levels. In addition to the dissociation of water melocules, ionozation generates radicals also from the other melocules, which in turn attack protein structures and change them. The DNA and RNA being carriers of the genes and responsible for cellular control mechanisms do have protective mechanisms and a certain degree of repair capacity, which again depend on the rate of reproduction. The most sensitive reaction on an organic level aside from the hemogenetic formation is found in the human lens (ICRP 40, 1984).

Alpha-rays occurring naturally have only a small range below 0.2 mm, whereas beta-rays of higher energy can readily penetrate to the lens. Gamma-rays penetrate the eye, thereby diminishing in strength depending on the energy.

What is the reason for the sensitivity of the lens to ionizing radiation? The lens is isolated from direct blood circulation with all consequences. It is a closed cell system which grows for nearly a lifetime.

The pre-equatorial, germinative epithelial cells are damaged. Proliferation and differentiation of the lens fibre cells and crystalline are disturbed (Bergeder et al. 1982).

Which cataract threshold doses for ionizing rays can be given today? As for the lens the energy dose for a single exposure is 2 Gy depending upon the assessment factor.

When observed in fractions the effective dose is elevated.

The other parts of the eye need an energy dose at least 10 to 15 times higher to induce radiation damages. The question then arises: Can the portion of ionizing rays pose a danger to the eyes of flight personnel?

While the effective dose of natural radiation exporsure at sea level is approx. 30 mrem (0.30 mSv) per year, it is twice as high at an elevation of 2000 m (UNSCEAR 1982).

At an altitude of 12 km we are exposed to approx. 0.4 mrem per hour, i.e. to approx. 40 µSv or 4 mrem after a ten hour's flight. A pilot flying 250 hours per year at such an altitude accumulates an effective dose of approx. 10 mSv or 1 rem. Because of the fractionated dose over a long period of time the threshold value triggering off a cataract is not nearly reached.

Radiation damages to eye lids, conjunctiva, cornea, retina, and optic nerve can only be established, if the energy doses reach 30 - 50 Gy during fractionated radiation. These are values which an airline pilot even with high above average flight hours will never reach during his professional life.

Non-Ionizing Radiation:

Let us now turn to the electromagnetic radiation with wavelengths greater tha, which deposit energy under 6 eV in the biologic material.

Whereas ionizing rays display an unspecific behavior of absorption in biologic tissue, non-ionizing rays are bound by various absorbers depending on their wavelengths. Proteins, RNA, DNA in the UV-spectrum should be mentioned, between 400 - 800 nm ...anin (vision pigment), hemoglobin, xanthophyl (retina); above 900 nm most of the absorption takes place in water.

For short wave UV-light the eye is equipped with barriers, namely cornea, aqueous humor, and lens, which protect it well against ionization. Higher energies in the UV-spectrum and in the visible spectrum may trigger photochemical effects which may liberate radicals. In the long wave visible spectrum and above 800 nm unspecific thermal effects are predominant.

Light up to 320 nm is mainly absorbed by the cornea, while the lens absorbs between 320 and 400 nm.

The absorption capacity of the lens increasses with age. This is brought about by a mechanism which still hasn't been fully clarified, and by a protection for the retina in the blue-light spectrum. The underlying mechanism is yet to be solved.

Damages to Individual Structures of the Eye by UV-visible Light and Infrared Light

Well known are UV-damages to the cornea, such as photokeratitis, with a maximum damage at approx. 270 nm; all of us know the painful "sand in the eyes" experience with an inflamed cornea combined with tears and blepharospasm after several hours of latency.

This subject was covered in detail by the presentation of Major M. R. Lattimore entitled "Ultraviolet Radiation Effects on the Corneal Epithelium".

Pterygium and basaliom among others are increasingly attested to intensive UV-C and UV-B exposures.

Photomechanic damages to the lens:

Now lets turn to the photomechanic damages to the lens:
Tryptophan, thyrosin, phenylalanin, and cystein (Elstner 1987) are the absorbers for UV-A-light (Lermann S.). Diverse protective mechanisms such as ascorbic acid, alpha-tocopherol, superoxide dismutase and katalasis retard the development of toxic photo products. Under the influence of light an increased number of cataracta nuclearis can be observed since the antioxidative glutathion effects are absent in the nucleus (Andly 1987).

Also diverse drugs in conjunction with light may accelerate cataract formation (e.g. sulfonamides, cyclamates, etc. For details see Martignoni 1985).

The underlying mechanisms for the onset of photochemical lesions in the mammal retina were investigated by Ham et al. in 1984. Kremers et. al. 1988 and van Norren reported 2 categories of photochemical lesions in the retina. Synergistic reactions to oxygen and light are reported. The fundamental research work will be presented by van Norren tomorrow. Liberated oxygen radicals, hydrogen peroxide and Singulett-oxygen are held responsible for phototoxicity. These radicals attack the membranes of the outer layers of the photoreceptors. The result is a destruction of the outer segments of the photo receptors.

Further exposure to light may finally end in a complete annihilation of the photo receptors.
To protect the photo receptors there is not only an enzym-atic defense system consisting of catalases, peroxidases and SOD but also some special antioxidants, vitamine C and E. Positive changes to the toxic oxygen threshold are also brought about by cortisone and beta-carotene. Furthermore the regenerative ability of only slightly damaged photo receptors is remarkable. On the basis of these defense - and repair systems which try to keep up with damage elimination caused by light exposure it is extremely difficult to quantify light induced damages. Sliney, D. H. reports on it extensively in 1980 and 1984.

There are cues on the development of senile macula degenerations as a late manifestation of short wave light damages, but valid evidence is still missing. In contrast it is easier to present wavelengths and energy for threshold damages (Ham et al.).

It becomes evident that the sensitivity to damages is closely associated with the wavelength. Wavelengths below 530 nm pose a disproportionally high hazard for retinal structures. Therefore the retina seems to be particularly sensitive to blue light.

According to studies by Hawerth and Sperling color vision disturbances in the blue light spectrum are found already from a dose value of 0.5 J/cm2 on. For a timely research on this subject I should like to make reference to Prof. Arden, who has investigated disturbances in the blue-light spectrum with highly differentiated test methods.

Consequences for flight personnel:

The amount of solar radiation arriving at the upper edge of the atmosphere is about 1.35 kW/cm2 (solar constant).

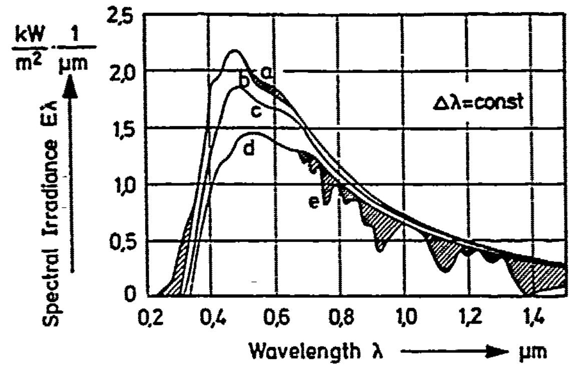

Fig 1: Spectral Distribution of Direct Solar Radiation

This illustration shows the extraterrestial solar radiation under a) (from Promet). Ozone, the gaseous layer at a height of about 20 - 35 km protects life from UV-A-B-radiation below approximately 290 nm (b). The Rayleigh-scattering further reduces the radiation intensity (c). (d) shows absorption and scattering by aerosol, water vapor and oxygen. (e). Depicts additional reduction factors, see hatching under (d). The direct soler radiation on an aircraft corresponds nearly to the lowest graphical curve. These values are slightly below the maximum permissible exposure (MPE). Additional reflective areas (ocean, cloud cover) come close to the zone of blue light spectrum damages. Is there then a hazard of too high an amount of light for the eye?

The Transmission qualities of cockpit-canopies and visors:

The transmission losses e.g. through the clear-respectively dark visors are such as to prevent amounts of light exceeding the damage threshold from damaging the eyes even at an altitude of 10.000 meters, provided they are handled properly. Wavelengths shorter than 380 nm are blocked.

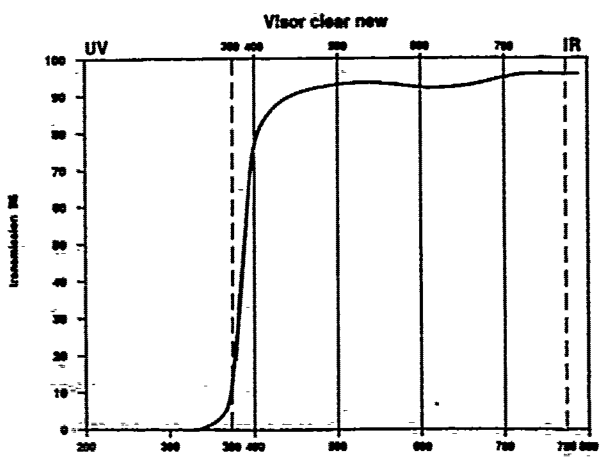

Fig 2: Wavelength-Dependent Transmission

The cockpit canopy of the Alphajet and the Tornado

have been designed regarding their transmission properties in such a way as to preclude damages under normal pilot behavior. This of course excludes intentional prolonged glances of more than 10 - 14 sec. duration directly into the sun, for then the MPE is exceeded. But this is generally known.
As a further comment may I state that neither long-distance airline pilots of the Lufthansa nor Bundeswehr pilots have ever complained about a photokeratitis or erythemas of sensitive eye lids which could have been attributed to flight duty. A significant increase e.g. of the cataract rate cannot be proven, which would be very difficult anyway since different ways of lifestyle, visits to solariums, duration of exposure to the sun while on vacation a.s.o. would have to be considered when estimating time of exposure. Older pilots have a natural protection because of a changed transmission behavior of the lens.

Summary:

With the current methods including color vision tests with the Hue-test 100 no eye damages in the blue-light spectrum of solar radiation could so far be verified in flight personnel. Protective measures through quality sunglasses or sun visors with a high filtering effect and a complete blocking in the UV-spectrum most likely provide adequate protection. Our previous experience, however, should not keep us from striving for refinement of examination methods especially in the "blue-light spectrum" in order not to overlook insidious damage. The point is to avoid phototoxic damage. It is our task to provide safety for the pilot; we can achieve this by an advancement of knowledge, measuring methods, and consequent actions.

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AIRCREW SUNGLASSES

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SUMMARY

The hazards of light are now better understood and it is imperative that aircrew, who may fly in ambient illuminance levels reaching 150,000 lux or greater, be provided with adequate protection. The primary hazards are from the C.I.E. photobiological bands starting at the ultra violet B and extending through to the infra red A although the latter is relatively unimportant. Potentially the most serious hazard is from the visible band below 500 nm; these highly energetic photons constitute the blue light hazard to the retina. The spectral transmittance of a sunfilter must take into account these hazards whilst at the same time not adversely affecting colour discrimination. A good sunfilter should not only protect the eyes but also improve visual acuity and contrast discrimination both in haze and glare conditions.

OCULAR HAZARDS OF SOLAR RADIATION

Solar radiation, as far as ocular effects are concerned, comprises only a small portion of the electromagnetic spectrum and extends, for practical purposes, from the short ultra violet to the far infra red (100 nm - 100 µm). As the damage to ocular tissues at threshold levels is wavelength specific, it is convenient to subdivide the spectrum into wavebands on the basis of their biological effect as recommended by the International Commission on Illumination (C.I.E.) (Fig 1).

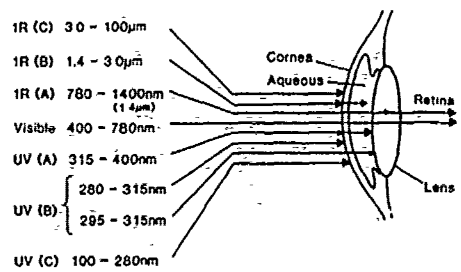

Fig 1. Spectral absorption characteristics of ocular tissues.

The ultra violet (C) extends from 100 - 280 nm and is largely absorbed by the upper atmosphere, very little is present in terrestrial solar radiation. It is also absorbed by nearly all transparent materials. The effects of UV(C) are confined to external tissues such as skin, conjunctiva and the cornea, where due to its very high photon energy it causes tissue death, although its penetrating power is low. Fortunately, in aviation, this wavelength band is unlikely to be encountered. UV(C) radiations are emitted by Excimer lasers and these are now used in refractive surgery (photo-refractive ablative keratectomy) to recontour the central area of the cornea with, so far, great success.

The ultra violet (B) extends from 280 - 315 nm and, although penetration is deeper than the UV(C), it is again, primarily, absorbed by external tissues where it causes photochemical 'burning' of the skin and the eye producing, after a latent period, an inflammatory condition. This most commonly occurs artificially as 'arc welding eye' or naturally as 'snow blindness'. Some of the longer wavelength UV(B) (295 - 315 nm) is able to reach the crystalline lens where it may initiate cataractogenesis. Wavelengths shorter than 320 nm are commonly referred to as the actinic ultra-violet.

The ultra violet (A) 315 - 400 nm. primarily affects the ocular lens where it may be involved in the delayed, up to 10 years, production of cataracts. The cornea is a secondary absorber of UV(A).

The visible light 400 - 780 nm. This wavelength band comprises a myriad of hues which commence in the violet and continue through blue, green, orange and red, ending in the deep cherry red. Sunlight contains a mixture of all the wavelengths which the eye can perceive. The shorter wavelengths at the blue end of the spectrum are more hazardous to the retinal photoreceptors than the longer wavelengths due to the more energetic nature of their photons.

In experiments with relatively long exposure periods, greater than 10 seconds, and relatively bright sources, blue light has been shown to be damaging and dangerous at lower levels than other bright sources. This constitutes the 'blue light hazard' which is now recognised with appropriate protection factors in codes of practice for eye safety.

The infra red (A) 760 - 1400 nm (1.4 µm). These wavelengths, like visible light, are refracted by the cornea and lens of the eye and may be brought to a focus on the retina. This radiation is invisible and as the retina does not possess pain fibres, damaging over-exposure may not be painful. It is thus capable of causing burns which are neither seen nor felt, although these are only likely to occur with laser sources.

The infra red (B) 1.4 - 3.0 µm and *infra red (C)* 3.0 - 100 µm wavelengths are primarily absorbed by the skin and cornea and cause a sensation of heat; painful burns could result. In practice, solar radiation burns from infra red (B) do not occur.

Mechanisms of Ocular Damage

For light to damage tissue it must be absorbed by that tissue (Draper's Law). When energy is absorbed rather than transmitted it can cause damage by photochemical, thermal or mechanical (acoustic) mechanisms. Solar damage is nearly always photochemical and may be acute or chronic. The other two mechanisms are usually associated with laser sources.

The first absorbing site in the eye is the cornea which filters most of the actinic ultra violet below 320 nm comprising the UV(C) and (B) bands, although, as previously stated, some of the longer UV(B) photons from 295 - 315 nm are able to traverse the cornea and reach the crystalline lens. The UV(B) and (C) and some of the shorter UV(A) wavelengths, when absorbed in the outer layers of the eye, can cause by photochemical mechanisms a photokerato-conjunctivitis. With appropriate treatment this condition normally resolves within 48 hours and, apart from the pain suffered the condition, is usually not serious. Should the damage extend in depth, a permanent opacity may result with the possibility of a severe visual decrement.

The second absorbing site is the crystalline lens and this predominantly filters the longer UV(A) photons from 315 - 400 nm, although some of the longer wavelength UV(B) photons are also filtered by the lens. The risk of any significant amount of UV solar radiation reaching the retina is small, but the retina can be damaged by exposure to powerful sources of UV(A) such as a helium cadmium laser (Zuchlich, 1984). The lenticular photochemical effects of these wavelengths can produce a cataract where the damage is usually evident in the anterior capsule, the underlying subcapsular epithelium and the anterior cortex. The absorption of UV increases with age due to the increasing presence of a yellow pigment in the lens which may be a by-product caused by the effects of UV(A) on tryptophan. Whatever the cause, this yellow pigment helps to protect the retina against the blue light hazard but increases the incidence of cataractogenesis.

The third and most important absorbing site is the retina and in particular the melanin in the retinal pigment epithelium (RPE) and the pigments in the outer segments of the photoreceptors. Kremers (1988) argues that bleached visual pigment may be an alternative to melanin. Although the retina is primarily at risk from visible wavelengths from 400 - 780 nm, it is also at risk from near infra red wavelengths extending out to 1400 nm (1.4 µm), as these wavelengths, like those in the visible band, can be brought to a focus on the retina. More accommodation (+0.5 to +1.00D) is required to focus near infra red wavelengths than is required to focus those in the visible band. The retinal hazard from the invisible near infra red wavelengths would at first sight seem severe. In practice, the hazards of IR(A) from solar radiation are small, even when using visors or sunglasses which attenuate visible light but not the IR(A). Such filters in attenuating the visible band produce pupillary dilatation, and allow the unfiltered IR(A) unimpeded access to the retina. Retinal damage, however, does not normally occur. The so-called eclipse 'burns' which can occur when the sun is viewed through inadequate filters, are in fact photochemical in origin. They are caused by the shorter blue wavelengths that are at their maximum when the passage of solar radiation through the atmosphere is short, as when the sun is overhead. When the sun is low on the horizon the shorter wavelengths, but not the IR(A), are preferentially filtered by the atmosphere and it is uncommon for damage to occur. The macular pigments themselves also provide a selective absorption of blue light and thus give a measure of protection. Solar damage from infra red A is rare, although it is obviously foolish to stare at the sun under any condition, even when it is setting. Man made sources of IR(A) such as the neodymium yag laser are, of course, capable of producing true retinal burns.

Blue Light Hazard

It is an historical fact that viewing a solar eclipse through inadequate filters has been known, since the time of Galileo, to cause a retinal 'burn'. More recently it has been demonstrated that damage is produced even when the estimated temperature rise of the retina is inadequate to cause a true burn. Photochemical processes must, therefore, be responsible for the pathology. Collecting and magnifying optics such as binoculars gather the light flux according to the diameter of their entry lens and magnify the size of the image on the retina. This collection and focusing of solar radiation will result in an increased optical gain on the retina, which may cause a true thermal burn.

It has been shown by Ham (1976) that blue light, with its high photon energy, is capable of producing retinal pathology at power levels which are well below the retinal burn threshold. Ham used a helium cadmium laser emitting at 441 nm, although for practical purposes the hazard extends from 400 - 500 nm. The hazard of the blue component of white light has been confirmed by animal experiments and by epidemiological studies of people exposed to high light levels. This occurs, for example, in eskimos who receive not only intense light from above but reflected light from the ice below. A similar effect is present in aviation when the reversed light distribution is caused by reflections from clouds below the aircraft.

Blue light damage is additive from repetitive long term exposures (>10 s). This not only applies to high level solar radiation but to lower level prolonged exposure to man made sources of illumination, some of which emit at daylight intensities. Many individuals choose to spend long periods in brighter surroundings than are necessary for good vision, particularly with fluorescent sources which are richer in blue wavelengths than are incandescent lights.

The photochemical damage caused by blue light is normally divided into two categories. The first category is damage caused by prolonged exposure to low levels of light containing blue wavelengths where the effects are primarily on the cone photoreceptors. The early symptoms are likely to be impairment in blue/green colour discrimination. Such impairment of colour vision is now being found in ophthalmologists who use the argon laser to treat retinal pathology (Gunduz, 1989). If unprotected they may be repeatedly exposed to low level reflections of the short wavelengths of the argon laser. In the second category damage is caused by shorter exposures to higher levels of blue light and here the effects are primarily on the RPE. The blue photons are preferentially absorbed by the melanin in the RPE whose spectral absorption in the visible band, is at a maximum in the blue. This can cause dysfunction of the RPE (vide infra) and is what is commonly known as the 'blue light hazard'.

Chronic Light Damage

Many workers notably Noell (1966) and Marshall (1972) have demonstrated that long term exposure to light in excess of 10 seconds can cause damage by photochemical rather than thermal processes. Marshall demonstrated cone degeneration in pigeons exposed to fluorescent light at a moderate luminance (3000 cd/m^2) for only 8 h. This luminance is equivalent to that encountered on a cloudy winter day in UK. It is at first sight surprising that damage should result; but in Marshall's experiment the pigeons' total field of view was of uniform brightness unlike that of their normal mixed visual environment. This work has been repeated in monkeys by Sykes (1981).

The outer segments of the cone photoreceptors, unlike the rods, renew their membranes containing the photopigments very slowly, in a unitary fashion. The total process may take up to a year, whereas in the rods this process is completed every two weeks. The rod mechanism is much more efficient in repairing light damage than is the cone mechanism and it has been found (Marshall, 1985) that there is little evidence of loss of rods until over 70 years of age. Evidence of loss of cone membranes and cone cells themselves is, however, apparent above the age of 40 years. This relative inefficiency of the cones in repairing damage caused by light is an 'ageing' process which is particularly apparent at the macula. The macula, with the fovea at it's centre, is the area of the retina which is predominantly composed of cone photoreceptors. It thus provides the eye with it's ability to resolve detail and to provide fine hue discrimination. The loss of macular function can cause a severe visual impairment which normally becomes evident in the sixth or seventh decade. It is probable that those who are repeatedly exposed to higher light levels than the norm will 'age' their retina more rapidly. This is particularly relevant to unprotected or inadequately protected aircrew.

Macular Degeneration

Excessive exposure to blue light will cause the photo- pigments in the outer segments to overbleach; this process, in conjunction with oxygen, causes the metabolic production of toxic free radicals. These free radicals attack photoreceptor cell membranes causing them to degenerate; the cones suffering first. The melanin in the RPE acts as a limiting mechanism, as it has the ability to neutralise free radicals. In so doing the RPE cell itself may be damaged or destroyed, and its supportive role may fail; this is also accelerated by the effects of direct absorption of blue light by melanin. This loss of function can result in the accumulation of photoreceptor waste products in the RPE cells which, are extruded together with undigested phagosomal remnants onto Bruch's membrane. When the aggregations of waste products are large enough to be ophthalmoscopically visible they are known as Drusen (Fig 2). Should the process continue it may progress to a senile degeneration of the macula, in which the photoreceptors are destroyed by the accumulation of waste products, that separate the RPE from its metabolic support by the choroidal blood supply. Should the condition progress it may result in a disciform degeneration of the macula. Choroidal vessels proliferate through Bruch's membrane into the RPE producing haemorrhages and causing it to fail in it's role as the barrier between the choroidal blood supply and the retina. The end result is a central scotoma causing a profound loss of vision. The ophthalmoscopic appearance is that of a raised circular area of fibrous tissue centred on the fovea and normally about 3 disc diameters (4.5 mm) across.

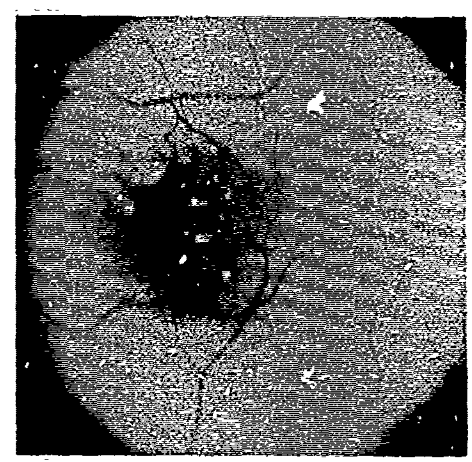

Fig 2. Drusen on Bruch's membrane.

SUNFILTERS

Sunfilters, both spectacles and visors, should be designed so that they are of the correct optical density to minimise glare. They should also provide maximum visual acuity, contrast enhancement and hue discrimination. The spectral transmittance should protect the wearer against the hazards of light, whilst at the same time not impairing the recognition of colours of importance in aviation. It should, also, assist in penetrating haze. The filter material must be of high optical quality, robust, scratch resistant and should protect the wearer in the event of bird strike or collision. Finally, the filters must fit securely and precisely, without gaps, within their frames and the filters must not dislodge on impact. The sunglasses should, also, be thermally stable and non-flammable.

Optical Density

Glare protection is provided by tinted spectacle filters. The luminous transmittance of the filters should be between 10 - 15% (optical density 1.0 - 0.8). Such a density will attenuate the highest luminances likely to be encountered in aviation (<10^6 cd/m^2) to an acceptable level, whilst at the same time reducing the commonly encountered luminances in Europe (10^4 - 10^5 cd/m^2) to between 10^3 - 10^4 cd/m^2 at the cornea, which is the region in the luminance range that is optimal for visual performance. Fixed densities can never, with widely varying external luminances, always provide the correct attenuation of light but an optical density of 0.8 - 1.0 is a reasonable compromise. The variation in density between corresponding points on each mounted filter must be matched to within +/- 0.04 in order to avoid false spatial projection (Pulfrich effect).

Filter Materials

It is important that filter materials should be of high optical quality and resistant to fracture on impact. The mass of the lenses should be low. The material of choice is either polycarbonate or CR39 resin. Glass, although usually optically excellent, is normally heavy, and does not possess the impact resistance of polycarbonate, even when toughened.

Polycarbonate is unsurpassed in terms of impact and shatter resistance; it is lightweight with a high refractive index which ensures that powered filters for ametropes are thin. Its optical quality is good although, on occasion, inclusions are found in injection moulded lenses.

Regrettably, the high impact resistance of polycarbonate is coupled with the lenses being relatively soft and therefore easily scratched. It is essential, therefore, that polycarbonate lenses are treated with a hard anti-scratch coating, if the problems of haze and veiling glare due to scratches are to be avoided. Polycarbonate suffers one other disadvantage in that its 'V' factor is low (30) as against CR39 resin (58). This low 'V' factor can cause the dispersion of white light into its spectral colours causing a slight loss of definition; only seen in high powered corrective filters.

CR39 resin can be formed into filters of excellent optical quality although they may need to be slightly thicker when powered, than those made of polycarbonate due to its lower refractive index (1.499) against polycarbonate (1.586). Due to the higher 'V' factor, dispersion is not a significant problem with CR39 and the material can therefore be formed into higher powered filters. The impact resistance of CR39 is good but not as high as polycarbonate; however its scratch resistance is significantly better than uncoated polycarbonate.

Spectral Transmittance

The spectral transmittance must not impair colour recognition external to or within the cockpit. It is imperative that the transmittance of UV(A) and the actinic ultra violet is kept to the minimum. It should not exceed 1%. The transmittance in the visible band 500 - 780 nm should be as flat as possible to avoid adverse effects on hue discrimination. To reduce the blue light hazard the transmittance of the shorter wavelengths of the visible band in the spectral domain 400 - 500 nm must never exceed the value for the luminous transmittance and should, preferably, gradually decline from 500 - 400 nm, without any spikes in its transmittance spectrum. The *red signal visibility factor* which is the ratio of the transmittances of red and white light should be in the range 0.9 - 1.2 and the *violet factor* which is a measure of the transmittance of light at 420 nm and 460 nm divided by twice the value of the luminous transmittance, should not fall below 0.5 (Australian Standard, 1983). Compliance with these standards should avoid any problems in the perception of red and blue/green visual displays. Furthermore, as haze is largely scattered blue light the lowered transmittance in the blue should also assist vision in hazy conditions.

The transmittance in the IR(A) should, ideally, not exceed the value of the luminous transmittance. This is easy to achieve with glass filters, but is difficult to achieve with tinted visors fabricated from polycarbonate or other plastics; it is a desirable, but not an essential requirement.

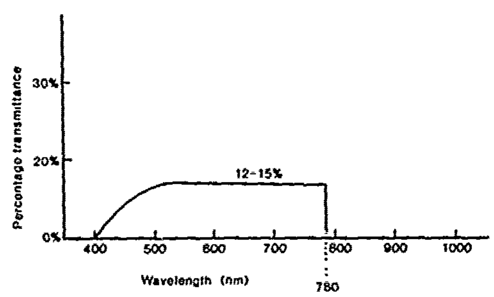

Fig 3. Spectral plot of an 'ideal' sunfilter.

The likely tint to meet the above standards will probably be a dyed in the mass grey or brown. Figure 3 shows what is considered to be an 'ideal spectral plot for a sunfilter whilst (Figs 4 & 5) are the spectral plots of an acceptable filter.

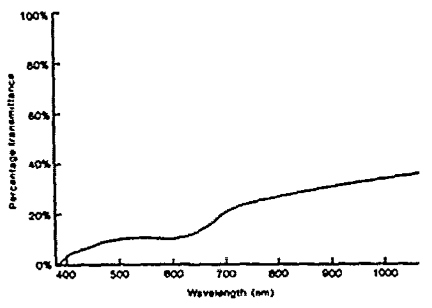

Fig 4. Spectral plot in the visible and the I.R.(A) of an acceptable sunfilter.

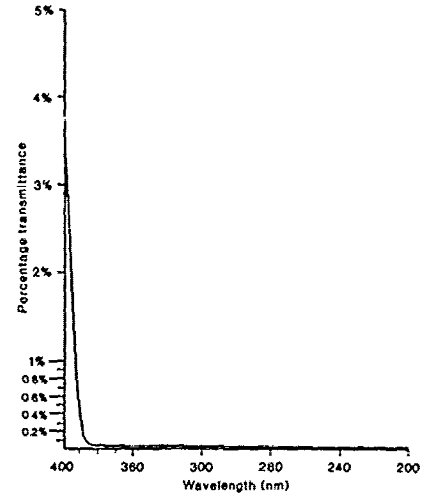

Fig 5. Spectral plot in the UV (A,B and C) of an acceptable sunfilter.

Optical Quality

It is important that the geometrical optical quality of transparencies designed for aircrew use should be high, if visual performance is to be maintained. The following specification should help to ensure this objective.

The spherical power should not be in excess of +/- 0.06 m^{-1} from plano, and the difference in power between any two meridians at 90° with respect to each other should not be in excess of +/- 0.06 m^{-1}. The prismatic power of unmounted oculars at their centres should not exceed 0.12 cm/m. The total algebraic difference between two mounted oculars must not be in excess of 0.25 cm/m in the vertical nor in the horizontal, base in or base out. The standard for base out prism is stringent due to the accommodation convergence synkinesis. The convergence necessary to overcome the prismatic error could result in the associated accommodation reducing distance visual acuity. This horizontal prismatic requirement would exclude 'wrap around' filters with a significant dihedral unless compensatory prisms were incorporated. Any optical distortions likely to degrade vision are unacceptable.

Veiling glare is a great problem with any optical transparency as it reduces contrast. It can be caused by inherent haze in the filter which, ideally, should not exceed 0.5% but in practice around 1.0%, may have to be accepted. Any transparency should be scratch resistant, to minimise scattered light from abrasions and this may require a polysiloxane coating. Anti-reflection (A/R) coatings, usually multicoatings to be effective, are also a valuable means of reducing veiling glare from reflections - a prevalent condition in many cockpits. These coatings may also reduce abrasions and scratches if the A/R coating is hard or combined with a polysiloxane layer.

Powered Filters

Powered sun filters, for ametropic aircrew, pose a special problem in addition to the 'V' factor previously discussed. Positive lenses, for the correction of hypermetropes, will be thicker at their centres than at their periphery whilst the reverse applies to negative lenses for the correction of myopia, which are thinner at their centres than at the periphery. The extent of this variation in thickness will differ with the power of the correction and the refractive index of the lens material. If lenses are dyed in the mass, (as unpowered filters should be to avoid bright shafts of light due to scratches in a surface dye) the transmittance will vary between their optical centres and the periphery. This may be unimportant with low powered lenses but could be significant with higher powered lenses fabricated from a material of low refractive index. It may be advisable to use surface dyed filters on such high power lenses but it is difficult to obtain surface dyed lenses with the desired spectral attenuation, especially in the red and near infra-red. Complaints have been made by aircrew of the difficulty they have experienced in distinguishing between red and amber warning lights, when wearing surface dyed sun spectacles with an increased transmittance above 600 nm.

Frames

It is important that frames be correctly chosen. They should be made of corrosion resistant, robust, non-allergenic, approved, materials; metal frames are recommended as the glazing rims can be thin to minimise intrusion into the field of view (FOV). All joints and screws should be designed, constructed and assembled to ensure their integrity under stress including impact; lock nuts may be necessary. The fronts and eye shape should be designed for maximum FOV and compatibility with aircrew protective helmets and oxygen masks, if worn. Adequate provision for air circulation to minimise misting must be allowed. The sides should be slim to avoid discomfort from close fitting helmets (not ficted with a tinted visor). They should be designed to allow easy donning and doffing in flight and to minimise any distortion of ear seals with a consequent loss of sound attenuation. Anatomically contoured, flat, slim, 'hockey stick' ends are recommended

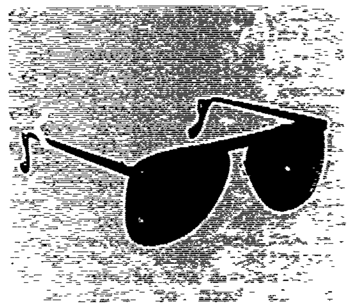

Fig 6. Frame suitable for aircrew wearing protective helmets.

whenever helmets are worn (Fig 6). Plastic covered hockey stick ends are appropriate when helmets are not worn (Fig 7). The frame should not deform in use and be free of projections, sharp edges or other features which could impair comfort. The frame should be treated so as to minimise reflections, for example matt black chrome. The frame/lens combination must, also, not degrade under the extremes of ambient temperature or chemical contamination.

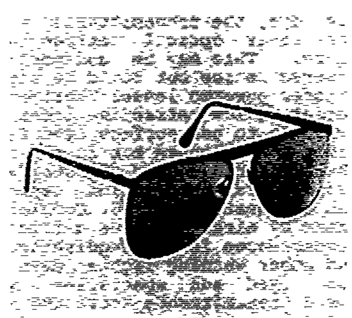

Fig 7. Frame suitable for aircrew not wearing protective helmets.

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LASER PROTECTION WITH IMAGE INTENSIFIER NIGHT VISION DEVICES

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SUMMARY

Current military ranging and targeting technology employs high power laser systems which can seriously damage the retina of the eye. Based on eye anatomy and function, three critical central retinal regions which must be protected - fovea, macula and peripapillary zone (1 to 2 degree annulus surrounding the optic disc) - are included in a circular area with a 25-degree radius. In the aviation community, barrier-type laser protection inherent with night vision devices (NVDs) was thought to be adequate. The NVD' barrier protection exceeds the recommended 25 degree minimum only when the eyes are in the primary (straight ahead) position. With normal scanning eye movement, critical areas of the retina become exposed to laser damage. Continuous laser protection for the central retina will require either a mechanical obstruction or a laser protective spectacle or visor which covers at least 90 degrees. The mechanical laser protection provided by NVD wear alone is not adequate to protect the aviator.

BACKGROUND

Current military ranging and targeting technology employs high power laser systems. Since coherent (laser) light with wavelengths in the visible and near infrared can seriously damage the retina of the eye, laser retinal injury has been the subject of many studies. The results of these investigations are used by various agencies to recommend laser eye protection.

The fovea of the eye, the region of the retina which provides maximum visual acuity is most sensitive to the effects of high energy photic stimulation. Since loss of function can be devastating to aviators requiring fine resolution, most studies recommend limiting direct exposure to this region. Outside the fovea, damage from accidental or intentional laser exposure is expected to have an insignificant effect on visual acuity unless a vitreal hemorrhage or retinal edema either blocked light from reaching the fovea or distorted vision by disrupting the organization of photoreceptors[1].

Since Army aviation missions place aviators in an environment prone to laser exposure, the development of laser protection is a compelling concern. The two vehicles presently available for laser protection are spectacles and helmet visors. Laser protective visors, usable during day flight, are not compatible with the Aviator's Night Vision Imaging System (ANVIS) since it requires movement of ANVIS far enough away from the eyes that the field-of-view (FOV) is reduced to unacceptable dimensions.

During NVD-aided night flight, the NVD provides barrier-type laser protection, i.e., physically block the laser light. The NVDs protect only the central area of the retina while the user views the environment through the device. This leads to the perception that foveal exposure to damaging laser sources can occur only during infrequent "looks" under or around the NVD to view the environment unaided. In view of this and the belief that extrafoveal laser-induced damage is not as devastating as foveal damage, the use of additional protection is viewed as unnecessary.

Even though NVD-compatible spectacles are available, some aviation community members are convinced that the NVD provides a sufficient level of protection.

RETINAL FEATURES

Anatomically, the macula lies near the posterior pole of the eye (Figure 1). Within this area lies the fovea and the vascular-free foveola. When viewing an object directly, the image is focused on the fovea. The dimensions of the macula and fovea vary depending on the metric used, e.g., density of cones, rod-free area, or vascular-free region, and on whether the anatomical or clinical designation is used[2]. For this report, diameters of 5 degrees and 12 degrees will be used for the fovea and macula, respectively[3].

The central retina covers an area which extends 25 degrees from the center of the fovea, and the peripheral retina covers the remainder of the field[4]. The most notable landmark in the central retina is the optic disc, or the optic nerve head (Figure 1). At this location nerve fibers from the retina converge to form the optic nerve which carries visual information out of the eye. The high density of photoreceptors in the macula area produces a large bundle of nerve fibers (papillomacular bundle) which courses nasally from the macula to the temporal side of the optic disc (Figure 2). The papillomacular bundle of nerve fibers is important because it carries visual information from the macula. Damage at any point along the nerve fibers carrying foveal information will result in a scotoma and degraded acuity. Thus, while military related laser injury studies primarily address the effects on central vision, i.e., damage to the fovea, extrafoveal damage can affect central vision.

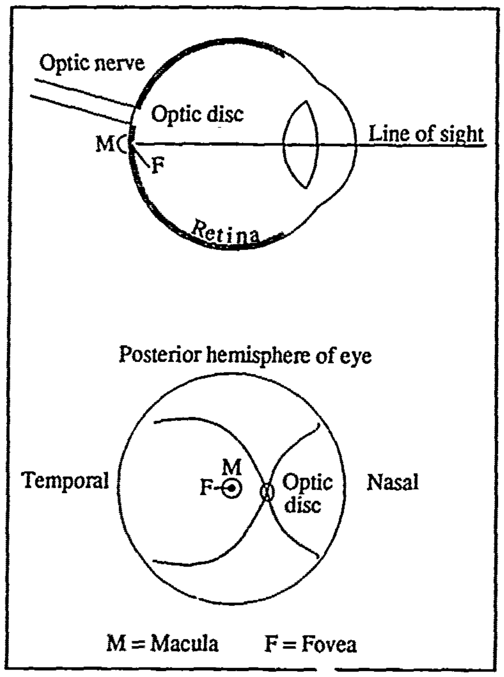

Figure 1. Schematic of the right eye. Two views show the locations of critical regions - fovea, macula and optic disc.

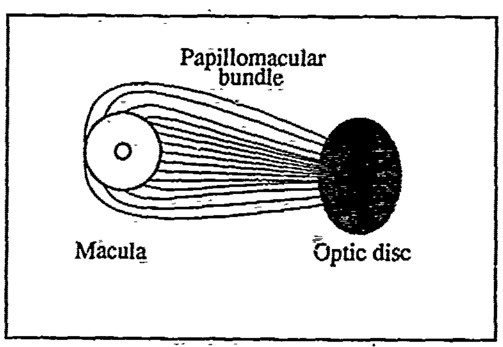

Figure 2. Papillomacular bundle. Nerve fibers course from the macula to the optic disc.

RETINAL DAMAGE FROM MEDICAL LASER USE

With medically indicated laser treatment of the eye, e.g., use of laser to treat retinal neovascularization, there are specific precautions regarding treatment of certain areas of the retina. These areas include the papillomacular bundle of the nerve fiber layer, the optic disc and the peripapillary area, i.e., the region surrounding the optic disc[5,7].

Attempts to use laser energy to coagulate vessels either on or above the optic disc (epipapillary), and around the optic disc (peripapillary), have resulted in central scotomas and vision loss. In one study[5], peripapillary treatment resulted in a central scotoma with acuity reduced to 20/200. Epipapillary treatment resulted in a central scotoma with an acuity decreased from 20/20 to finger counting (worse than 20/1000). In a more recent report, a laser burn of the peripapillary zone resulted in a central scotoma with acuity at 20/200[8].

One might argue that the medical use literature contains case studies of complications arising from laser damage to pathological eyes, and such damage is less likely to occur in healthy eyes. However, investigations of laser induced retinal lesions on human eyes and animal models provide histological evidence of damage mechanisms consistent with laser energy absorption by pigmentation[6,7,9].

RETINAL DAMAGE MECHANISMS

The primary damaging effects of laser on the eye are classified into three major categories - photochemical, thermal and ionizing[2]. The potential for immediate reduction in visual acuity associated with thermal and ionizing damage makes these mechanisms militarily relevant.

Photocoagulation is the only important thermal effect when considering retinal damage. This can be produced by laser light having transmission spectra matching absorption properties of available retinal pigmentation, e.g., melanin, hemoglobin, and xanthophyll. Light absorption by retinal pigment and subsequent emission of energy in the form of heat coagulates surrounding tissue. Among the group of lasers capable of photo-coagulation are argon, krypton, dye, ruby, frequency-doubled neodymium and neodymium/YAG lasers.

Photodisruption is a term used to describe the ionizing effect produced by neodymium/YAG lasers. The extremely high energy flux disintegrates the tissue into plasma at the focus point. Secondarily, shock and acoustic waves produced mechanically disrupt adjacent tissue[2]. This effect is not limited to pigmented retinal tissue as is the thermal effect.

These two damage mechanisms form a basis for exploring damage effects on two extramacular retinal areas, the papillomacular bundle and optic nerve.

PAPILLOMACULAR BUNDLE

The nerve fibers which form the inner layer of the retina are transparent to light. These fibers allow laser energy to pass through to the outermost layers of the retina, e.g., pigmented epithelium. The nerve fiber layer (NFL), including the papillomacular bundle, is located a relatively safe distance from the pigmented epithelium, the site of most energy absorption. Therefore, the thermal effect to the nerve fibers is minimal for most locations. However, damage to the NFL has been reported when photo-coagulation of arterioles and venules has been attempted[6,9]. Since these vessels are located within the NFL, the damage follows laser energy absorption by hemoglobin. The heat emission from a vessel occurs in a radial pattern (Figure 3) with consequent nerve fiber damage adjacent to the vessels (perivascular). This effect can occur in the absence of destruction to the blood vessel. While the likelihood of a direct vascular irradiation may seem remote, in a group of accidental laser exposures from non-ionizing lasers (N=12), 50 percent resulted in sufficient vascular damage to cause a retinal hemorrhage[1].

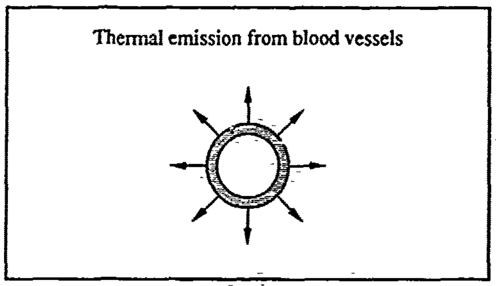

Figure 3. Laser light absorbed by retinal pigment is emitted as thermal energy (arrows). Thermal energy is emitted radially from blood vessels.

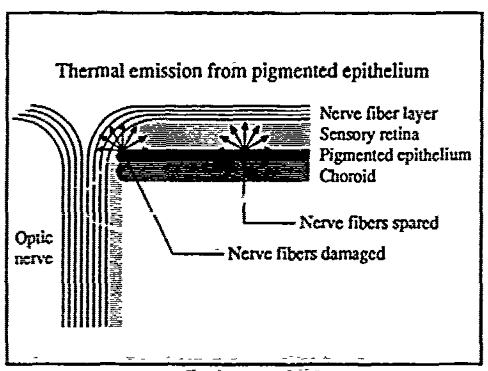

Figure 4. Laser light absorbed by retinal pigment is emitted as thermal energy (arrows). Thermal emission adjacent to optic disc can destroy nerve fibers.

The papillomacular bundle nerve fibers are at greatest risk at the optic disc. As the nerve fibers turn to enter the optic disc, the distance between the fibers and the pigmented epithelium is reduced (Figure 4). Laser irradiation of the peripapillary pigmented epithelium has been shown to produce central vision losses[7-8].

With the photodisruption effect, from a neodymium/YAG laser, for example, there is the potential for NFL damage and central vision loss. The severity of vision loss would depend on the location and extent of the damage to the papillo-macular bundle.

OPTIC NERVE

Optic nerve damage can occur in four ways. First, thermal damage can result from light absorption and heat emission by vasculature of the nerve head margin. Second, ischemic damage can occur when choroidal vessels adjacent to the optic disc are coagulated. Third, direct coagulation of nerve tissue will occur in the presence of an extremely high power flux density, i.e., resulting from a high power and a small spot size[2]. Finally, photodisruption at the optic disc will disintegrate never fibers. In any of these cases, a subsequent optic neuritis (inflammation of the optic nerve) would be accompanied by central vision loss.

RETINAL SENSITIVITY TO LASER DAMAGE

Based on the anatomy of the eye and complications associated with medical laser use, o.e author[2] classifies retinal sensitivity to photocoagulation with a scale of 1 to 5. The fovea is the most sensitive retinal region. The second most sensitive regions include the macula and a 1 to 2 degree peripapillary zone (Figure 5).

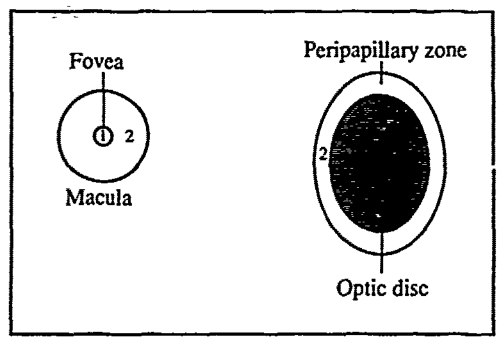

Figure 5. Sensitivity of retina to laser energy damage. The fovea is the most sensitive (1) area. The next most sensitive (2) areas include the macula and peripapillary zone.

When there is an operational/performance trad.-off which precludes full coverage laser protection for the eye, the minimum coverage acceptable must include the two most sensitive areas of the retina. A circular area which includes the most sensitive regions of the eye would cover the central retina, i.e., an area extending out to 25 degrees from the visual axis.

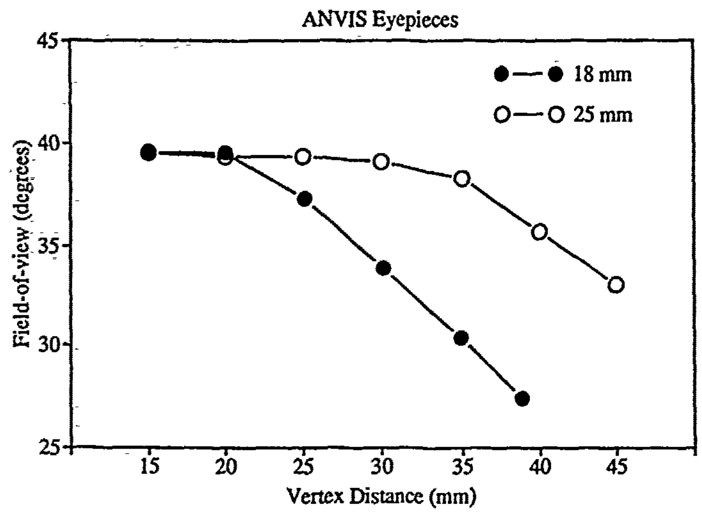

Figure 6. ANVIS field-of-view (FOV) versus vertex distance. FOV decrements for 18mm and 25mm ANVIS begin at approximately 20mm and 30mm, respectively.

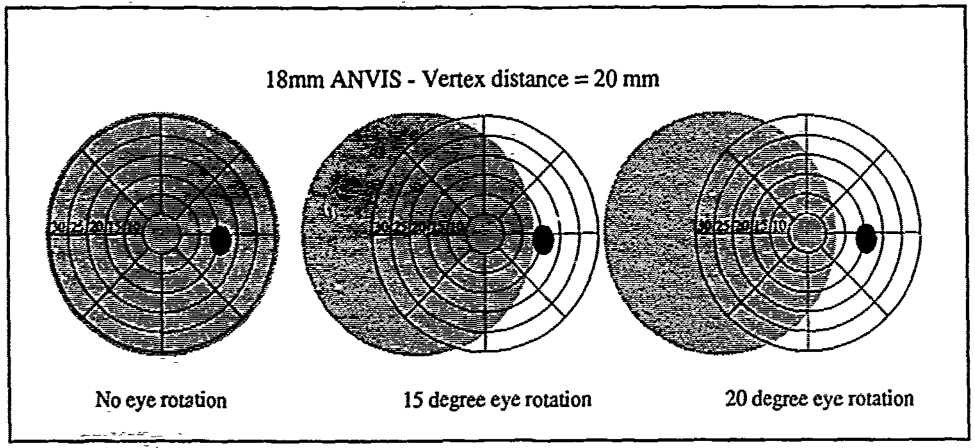

Figure 7. Effect of eye rotation on 18mm ANVIS protection. The optic disc is unprotected during both 15- and 20-degree eye rotations.

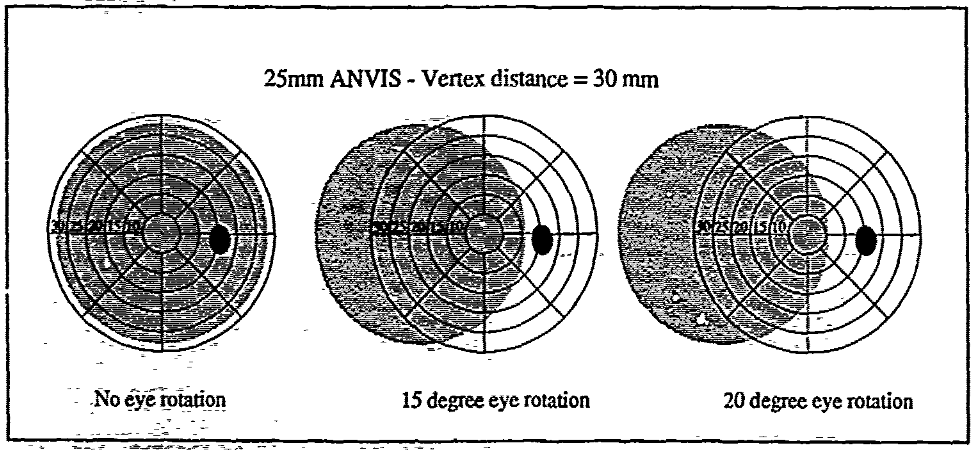

Figure 8. Effect of eye rotation on 25mm ANVIS protection. The optic disc is unprotected during both 15- and 20-degree eye rotations.

RETINAL GEOMETRY AND NVD PROTECTION

The normal binocular visual field covers an oval area with limits listed in Table 1. Visual field measurements usually are taken with the eyes fixed in the primary, or straight ahead, position. When the eyes move, the extents of the visual field increase by an amount equal to the ocular excursion. Under normal conditions, the eyes will move a limited amount before the head turns. Standard human factors reference sources[11] suggest a preferred limit of 15 degrees and a maximum limit of 20 degrees when designing visual displays.

Table 1.
Size of binocular visual field[3]

Direction	Angular Extent (degrees)
Temporal	100
Nasal	100
Superior	60
Inferior	75

NVD USAGE FACTORS

The protection provided by NVDs is limited by their physical dimensions and their positioning in front of the eyes. NVDs are usually adjusted by the aviator as far away from the eyes as possible while retaining the maximum field-of-view (FOV) of approximately 40 degrees. As the NVDs are moved further from the eyes, less head tilt is required to look under the device to view the cockpit instruments. The maximum FOV can only be achieved when the NVD is positioned within approximately 20 - 30 mm of the cornea of the eye (Figure 6). These distances are dependent on the type of eyepiece the device uses, i.e., 18 mm versus 25 mm ANVIS.

To compensate for the limited FOV, head movements must be substituted for eye movements when scanning the environment. Due to the increased head-supported weight, any increase in head movements will increase the aviator's overall workload. To avoid excessive head movements, aviators are taught[10] to use scanning techniques to view the imaged scene. With a 40 degree FOV, the eyes would theoretically turn 20 degrees before a head movement would be initiated.

Based on the above considerations, two NVD configurations were selected for detailed evaluation: 18 mm ANVIS worn at a vertex distance of 20 mm and 25 mm ANVIS worn at a vertex distance of 30 mm.

COMPUTER MODEL OF NVD PROTECTION

A simple computer model was developed to determine retinal coverage/exposure expected during normal NVD use. The major variables include eye relief of the ANVIS eyepieces (18 mm vs. 25 mm), expected vertex distances, outside diameter of the eyepiece, ideal and maximum eye excursions prior to head turn, and the locations of specific reference points of a standard eye.

Key values estimated by the computer model appear in Table 2, which describes the protection provided for two ANVIS configurations as they are expected to be worn, i.e., 18mm ANVIS at 20 mm vertex distance and 25 mm ANVIS at 30 mm vertex distance. When the eyes move from center, critical areas of the retina become exposed to laser damage. The areas exposed are indicated in Table 2.

Table 2.
Lateral laser protection provided by ANVIS

Eye rotation (degrees)	Lateral protection (degrees) 18mm ANVIS	25mm ANVIS
0	31.00	27.99
10	19.12	16.61 *
15	13.11 **	10.88 **
20	7.56 **	5.59 ***

* Partial optic disc exposure
** Optic disc exposed
*** Optic disc exposed + partial macula exposure

Vertical eye movement is not considered in this report because its impact on exposure is minimal. The central retina is protected by the helmet and the NVD mount during upward movements. When looking down, the partially exposed optic disk is protected by the structure of the aircraft, i.e., instrument panel.

Figures 7 and 8 illustrate the laser protection with an 18 mm and 25mm ANVIS, positioned 20 mm and 30 mm, respectively, in front of the eyes. The coverage exceeds the recommended 25 degree minimum, but only when the eyes are in the primary position. For both conditions, a critical retinal feature, the optic disc, is exposed as the eyes turn to the right 15 and 20 degrees.

Table 3 contains data which demonstrate the vertex distance effect on ANVIS as laser protection. At any vertex distance, the 25 mm ANVIS provides greater protection because of the width of its eyepiece assembly. However, the 25 mm eyepiece was designed to be worn further away from the eye. When worn at optimum vertex distances, 30 mm for 25 mm ANVIS and 20 mm for the 18 mm ANVIS, the 18 mm ANVIS has a slight protection advantage (Table 2). As the NVDs are moved further from the eyes, the portion of the visual field protected decreases.

Table 3.
Effect of vertex distance on protection provided by ANVIS

Eye rotation (degrees)	Vertex distance (mm)	Lateral protection from ANVIS (degrees) 18 mm	25 mm
0	15	36.59	41.90
	20	31.00	36.12
	25	26.71	31.60
	30	23.41	27.99
	35	20.80	25 08
15	15	18.48	24.21
	20	13.11	18.61
	25	9.14	14.29
	30	6.10	10.88
	35	3.72	5.90
20*	15	12.29	18.18
	20	7.56	13.01
	25	4.82	8.76
	30	3.71	5.59
	35	3.32	3.42

* As vertex distance increases, there is a loss of display field-of-view (FOV). The lateral protection listed is based on the maximum FOV for the vertex distance.

DISCUSSION

Under most viewing conditions, NVDs protect the macular area of the retina. Also, they will protect the critical areas of the central retina, for at least one of the eyes, at all times. For example, when the eyes rotate to the right during scanning, the optic disc and papillo-macular bundle of the right eye are exposed; while the disc and bundle of the left eye are protected. This points to the main disadvantage associated with relying on NVDs to provide laser protection, namely, the lack of continuous protection for the central retina of both eyes.

As shown in Table 3, the area of protection decreases as the NVDs are moved further from the eyes. Variations in individual anthropometry and use of multiple optical surfaces, e.g., protective mask with outserts, can move the NVDs far enough from the eyes to expose both the optic disc and part of the macula.

Aviators routinely use the look-under and look-around capability of NVDs to view outside the aircraft. Unaided viewing is recommended to obtain chromatic cues or to judge distances accurately[10]. .or lasers with visible outputs, peripheral retina detection/damage could result in the aviator directing an unprotected central retinal toward the source.

Laser damage to the NVD will require immediate transition to an unaided flight mode. This will leave the eyes unprotected until a laser visor can be deployed.

CONCLUSIONS

Continuous laser protection for the central retina, out to 25 degrees, will require either a mechanical obstruction or a laser protective spectacle or visor which covers at least 90 degrees. The mechanical laser protection provided by NVD wear is not adequate to protect the aviator. It must be understood by the operational community that the provision of laser protection by mechanical blockage using NVDs only protects the user from incapacitating macular injury. The peripheral retina would be unprotected and susceptible to injury.

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VALEURS LIMITES D'EXPOSITION APRES ILLUMINATION LASER : INFLUENCE DE LA LARGEUR DE L'IMPULSION ET DE LEUR TAUX DE REPETITION.

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RESUME

Ces travaux montrent l'importance de l'examen angiographique du F.O. pratiqué à J_0 pour apprécier les seuils de lésion rétinienne après illumination laser. Cette technique met en évidence l'inadéquation des valeurs seuil, proposées par divers organismes, lorsque le diamètre de l'image rétinienne s'accroit et lorsque le nombre d'impulsions augmente.

I INTRODUCTION

Les dangers présentés par l'emploi des lasers, en particulier les risques oculaires ont imposé la définition de valeurs limites d'exposition (VLE). Mais la formulation des VLE reste très complexe en raison des nombreux paramètres déterminant la délivrance de l'énergie ainsi que des critères permettant d'apprécier les seuils d'atteinte de la rétine. Plusieurs organismes (ANSI, ACGIH, IEC, OMS) ont publié diverses recommandations, mais il s'avère que certaines d'entre elles pourraient ne pas être justifiables si l'on prend en compte la dimension de la lésion rétinienne et son appréciation par des techniques angiographiques.

Nous présentons ici des expérimentations effectuées sur le lapin et le primate, concernant l'influence du diamètre de l'image sur l'effet d'une impulsion laser dans le spectre visible, domaine ou la précaution est la plus délicate à réaliser. D'autres résultats préliminaires montrent que ces VLE peuvent encore être modifiées dans le cas d'impulsions répétitives.

II METHODES GENERALES

II-1 La source

Deux dispositifs expérimentaux sont utilisés dans cette étude :

- Un laser pulsé à colorant (rhodamine 6 G) émettant des impulsions de 600 ns et de 10 mJ à 593 nm.

- Un laser YAG émettant à 1064 nm, ramené à 532 nm par un cristal de KTP, des impulsions de 40 ns à une fréquence réglable au coup par coup jusqu'à 1 KHZ.

Dans les deux cas, c'est l'image d'un diaphragme, qui prélève la partie centrale du faisceau que l'on forme sur la rétine de l'animal au moyen d'un système optique constitué d'un afocal précédant une lentille. Pour chaque banc expérimental, l'exposition énergétique rétinienne ($J.cm^{-2}$) est obtenue en multipliant l'énergie intraoculaire J (délivrée sur la cornée) par les coefficients T (transmission des milieux oculaires de l'animal à la λ considérée) et 1/S (inverse de la surface de l'image rétinienne en cm^2).

II-2 Les animaux

Comme pour les travaux antérieurs décrits dans la littérature, les animaux sont des lapins (Fauve de Bourgogne) et des primates (Rhésus et Cynomolgus). Les lapins sont prémédiqués à l'Acépromazine mais non anesthésiés alors que les singes sont anesthésiés à l'Imalgène. Chaque animal contenu peut subir une rotation centrée sur l'oeil traité permettant de multiplier les images sur une même rétine.

II-3 Les méthodes d'investigation

- Un examen ophtalmologique conventionnel (F.O), pratiqué à J_0 (15 mn après la lésion) et à J+1.

La présence ou la moindre suspicion de lésion est photographiée. Le plus faible dommage chez le lapin et le singe est une petite tache grise de la rétine traduisant une dépigmentation. C'est le critère de lésion.

- Un examen angiographique à la fluorescéine, injectée à J_0 dans la veine marginale de l'oreille du lapin et dans la saphène postérieure du singe.

Chaque tache révèlant la fuite de fluorescéine, donc l'oedème, est photographiée. Le critère de lésion est une tache jaune-verte bien délimitée. Sa persistance varie de quelques dizaines de minutes à quelques heures, et elle n'est plus détectable après 48 h.

II-4 Présentation des résultats

Nous avons déterminé les énergies (en énergie intraoculaire et en exposition énergétique rétinienne) correspondant à différentes probabilités de dommage pour chaque condition expérimentale. Les données sont enregistrées et traitées par la méthode des probits, déterminant ainsi la courbe de relation dose-effet et la dose efficace 50% (DE 50).

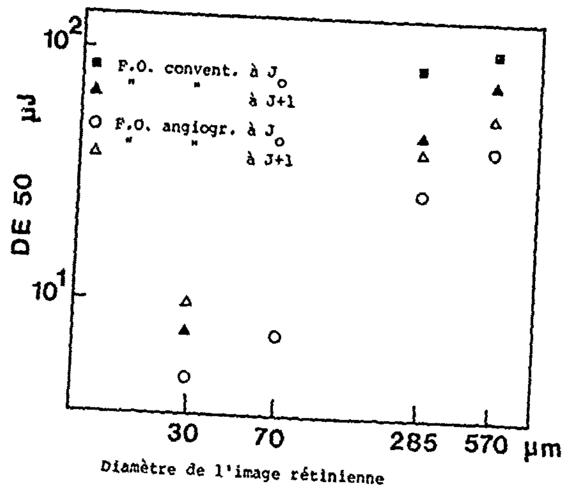

Fig.1: DE 50% déterminée pour différents diamètres de l'image rétinienne et pour deux techniques d'observation à différents délais après l'exposition.

III <u>SEUILS D'EXPOSITION A UNE IMPULSION UNIQUE</u>

L'étude montre l'importance de la méthode d'appréciation des lésions et du délai d'observation (figure 1). Quelle que soit la taille de l'image rétinienne :

- pour l'ophtalmologie conventionnelle, le meilleur délai se situe à J+1 après l'exposition ;

- pour l'angiographie à la fluorescéine, la meilleure observation se situe immédiatement après l'exposition.

Il est donc tentant de comparer les relations dose-effet obtenues par la méthode de fluorescence aux VLE proposées pour des images rétiniennes correspondantes chez l'homme.

- Pour une image de 30 µm (figure 2), assimilable à une source ponctuelle, la limite proposée en énergie intraoculaire à 593 nm est 25 fois plus faible que la DE 50 (et même < DE 0,1) estimée expérimentalement.

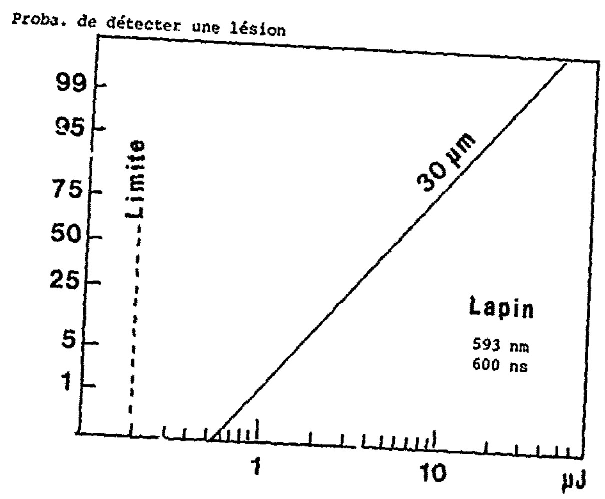

Fig.2: Probabilité de détecter une lésion par angiographie dans le cas d'une source ponctuelle (30 µm). Comparaison avec la limite proposée.

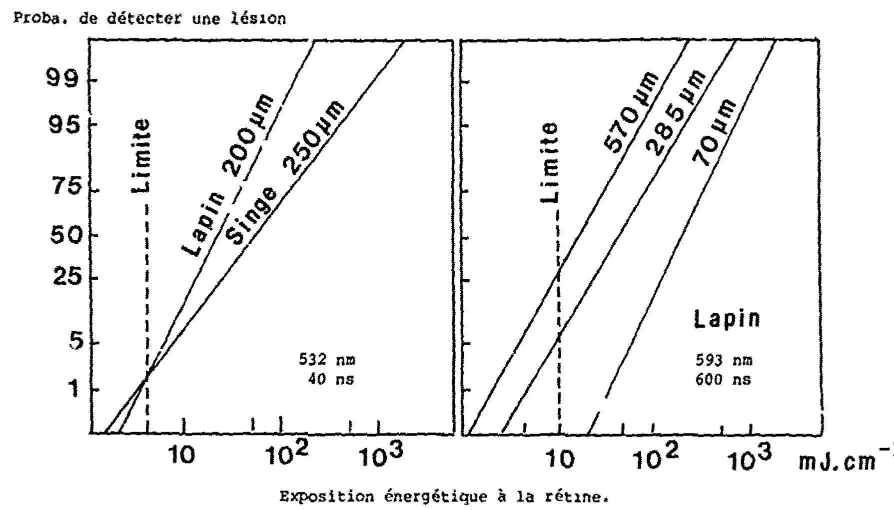

Fig.3: Probabilité de détecter une lésion par angiographie dans le cas d'une source étendue. Comparaison avec une limite proposée.

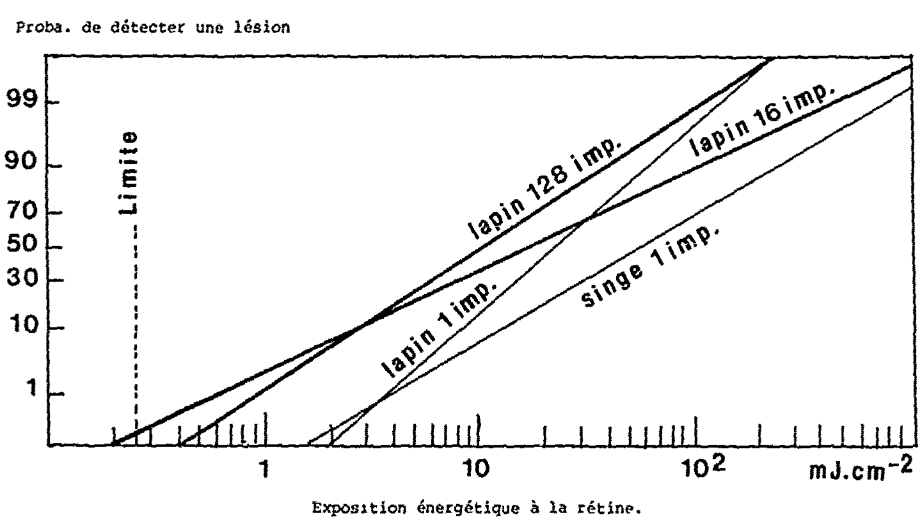

Fig.4: Comparaison entre les résultats déterminés chez le lapin et le singe pour des expositions de 1, 16 et 128 impulsions.

- Pour une source plus étendue (figure 3), toutes les DE 50 sont supérieures à la VLE rétinienne proposée (10 mJ.cm^{-2}). Mais pour des images de 285 à 570 µm, la limite correspond tout de même à des probabilités de lésion de 7 à 32 %.

- Pour une impulsion plus courte (40 ns à 532 nm) effectuée chez le lapin et le primate, en tenant compte des normes exprimées en fonction de la durée de l'émission, la limite correspond à une probabilité d'observer une lésion par fluorescence de 2 %.

Cet écart des DE 50 expérimentales par rapport à la VLE diminue considérablement lorsque le diamètre de l'image rétinienne augmente. Il en découle que les plus faibles énergies enregistrées capable d'induire un dommage rétinien sont très proches des valeurs limites : 4.74 mJ.cm^{-2} (532 nm, 40 ns, 200 µm) et 9,7 mJ.cm^{-2} (593 nm, 600 ns, 570 µm) à comparer respectivement à 4,3 et 10 mJ.cm^{-2}.

IV SEUILS D'EXPOSITION A DES IMPULSIONS REPETITIVES

De manière préliminaire, deux trains de 16 et 128 impulsions obtenues par le laser YAG ont été expérimentés chez le lapin. Les paramètres sont les suivants :

- . longueur d'onde : 532 nm,
- . durée de l'impulsion : 40 ns,
- . fréquence des impulsions : 1 KHZ,
- . angiographie à la fluorescéine à J_O,
- . diamètre de l'image : 206 µm,
- . 4 x 16 impulsions dans un oeil, 4 x 128 dans l'autre.

Les aspects des lésions sont en tout point comparables à ceux produits par une seule impulsion. Les DE 50 déterminées pour des impulsions multiples sont inférieures à celle obtenue pour une impulsion unique, mais la relation n'est pas claire du fait de la pente des droites (figure 4). Ces résultats sont compatibles avec la valeur limite calculée à 0,258 mJ.cm^{-2}. Quoiqu'il en soit, il faut s'attendre à une diminution de la valeur du seuil avec l'augmentation du nombre d'impulsions et des dimensions de l'image rétinienne.

V CONCLUSION

Ces expérimentations ont montré l'intérêt de l'observation par angioscopie à J_O pour déterminer le seuil le plus bas de lésion rétinienne.

La comparaison des résultats avec les limites proposées pour une impulsion unique fait ressortir que :

- Pour des sources ponctuelles (30 µm), la limite semble justifiée.
- Pour des sources étendues, la limite actuellement formulée en fonction de la durée de l'exposition représente un risque de lésion croissant avec la taille de l'image rétinienne.

Des précisions devraient être apportées par la poursuite des études sur les expositions à impulsions répétitives.

A TWO CLASS MODEL FOR PHOTOCHEMICAL DAMAGE OF THE RETINA

by

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INTRODUCTION

Tales about ocular light damage are very old. Socrates already warned against looking straight into the sun. In ancient times, just like today, looking in the sun is particularly popular during an eclipse. Occasionally, someone keeps a lasting memory of that event: Eclipse blindness. That light damage could also pose a military hazard was recognized at least a century ago. In the German journal Archiv für Ophthalmologie I found the following case history, presented by doctor Deutschmann. On the 21st of May 1882 he saw sergeant L. who admitted to have stared into the sun at the event of the eclipse on May 17. The sergeant's problem was "that he could no longer recognize the captain standing at the front". Not recognizing a superior may of course lead to serious military problems.

Thus, staring into a bright light source as the sun poses a well known hazard. I should emphasize that the sun, when viewed with the natural pupil, does not burn the retina in the sense that the damage is caused by a local increase in temperature (thermal damage). The process is of a photochemical nature, details of which will be presented later. Environmental light, however, might cause a more furtive danger. For modern man total exposure to light during life is increasing. We become older, artificial lighting levels increase and we become more exposed to sunlight. Man ventures to fly for hours above sunlit clouds, and in the tour of duty soldiers, whose ancestry is from the northern countries, may have to spend many months in a sunlit desert. Also, people enjoy spending up to weeks per year on sundrenched beaches. Recent literature considers it a serious possibility that the dose of light received during life is related to retinal damage at old age [1]. For lens damage in the form of a cataract, this is almost a certainty now [2]. The processes leading to long term damage are ill understood. To a lesser extent this holds for more acute light damage.

What we need is a basic understanding of the mechanisms involved in photochemical damage. In this paper I will concentrate on retinal light hazards mediated by photochemical processes, and related to exposures lasting from a few seconds to one or two days. In particular, I will argue that from a simple model with two retinal photosensitizers, the shape of the threshold curve for light damage can be predicted. Because the action spectrum for light damage is also known, from this model the damage threshold can be calculated for an arbitrary light source.

PHOTOCHEMICAL DAMAGE

Photochemical damage is an every day phenomenon. It causes the bleaching of curtains over time and the yellowing of a newspaper lying in the sun. Fundamental is the absorption of a photon in a pigment. In this connection such a pigment is called a photosensitizer. Natural photosensitizers in biological tissue are riboflavin, cytochrome-oxidase and retinol; other sensitizers are fluorescein, bengal rose, and chlorophyll. By absorbing a photon, the molecule gets exited into the singlet or triplet state. Energy may be transferred to other molecules, in particular via the long lived (up to a second) triplet state. With oxygen around, chances are high that oxygen radicals are produced. The retina is very vulnerable in this respect, because the eye's optical apparatus focusses beams of light there, and due to an extremely high metabolic rate there is an ample supply of oxygen. The very reactive oxygen radicals cause a chain of events finally leading to membrane damage. With very short wavelength light (UV-B and -C) a different path may be followed: Molecules may be directly damaged, without intervention of sensitizers.

Fortunately, this is not the end of the story. The eye, and in fact the whole body, has many scavengers of oxygen radicals. In addition, repair mechanisms exist for damaged tissue, and finally, the retina is well protected against short wavelength light. The cornea absorbs wavelengths around 300 nm, and the crystalline lens acts as an effective filter for longer wavelengths up to 400 nm (Fig. 1). Important radical scavengers are vitamins C and E, and in particular, the enzyme superoxide dismutase.

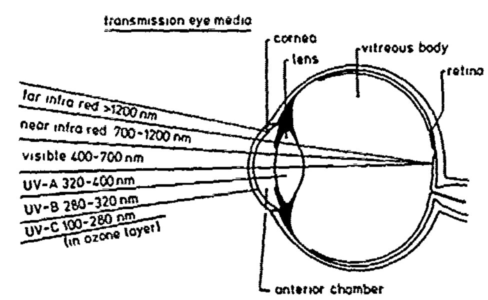

Fig. 1 Transmission of the eye media for the wavelength range 100-1500 nm.

SHAPE OF THRESHOLD CURVE

For the generation of damage, three aspects are of importance: The level of radiation, its spectral distribution, and the exposure time. A threshold curve relates irradiance level to exposure time for one kind of light. Criteria for just noticeable damage may vary widely, from functional impairment to just visible structural changes with the electron microscope. The action spectrum relates sensitivity for damage to wavelength of radiation.

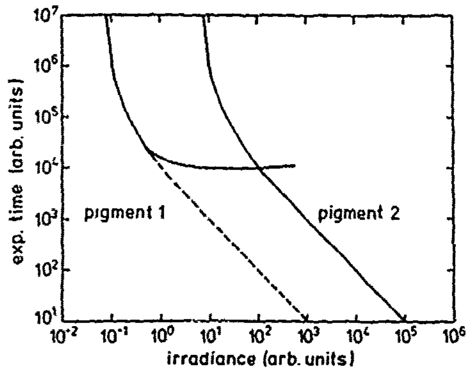

Fig. 2 Shape of the threshold curve for photochemical damage. For all stable pigments the shape is equal (pigment 2). For a pigment that bleaches under the influence of light, from a certain intensity on the curve levels off in a horizontal direction (pigment 1).

The fundamental shape of a threshold curve is simple. In a plot with irradiance along the horizontal axis and exposure time along the vertical axis it is a straight line with slope -1 (Fig. 2). This means that time and irradiance are exchangeable (or that their product is constant). At ever lower intensities, finally the rate at which tissue damage is produced, approaches the rate at which it is repaired.

For cornea as well as retina the time constant of tissue repair is abcut 4 days. The effect on the threshold curve is a bearing off to the vertical. At even lower intensities, the tissue can no longer be damaged. Quite likely, the retina contains more than one photosensitizer. A less sensitive pigment has the same threshold curve, but it is shifted along the horizontal axis. That sensitizer then is of no practical consequence, because damage is generated by the most sensitive pigment. Yet, a more complicated scheme is possible. When the photosensitizer is not stable in light, or in other words, is bleached by light (actually, changes into a pigment with a different absorption spectrum), the pigment starts to disappear at higher intensities. The threshold curve then bears off in a horizontal direction.

In the retina, the visual pigment is the only one that bleaches in light. Of course, it is also regenerated, but at very high intensities nearly all of it is in the bleached state. If we assume that the visual pigment is the most sensitive photosensitizer (Fig. 2, pigment 1), and another pigment is a stable, less sensitive sensitizer (pigment 2), this yields a scheme where at low intensities and long exposures threshold is set by pigment 1, and at high intensities and short exposures it is set by pigment 2. A quantitative analysis of this theory can be found in a publication by Kremers and van Norren [3].

In Fig. 3 theory is confronted with practice by reproducing all known literature data for white light, whereby differences in experimental conditions, like animal species and damage criterion, are ignored. Agreement between data and model is good.

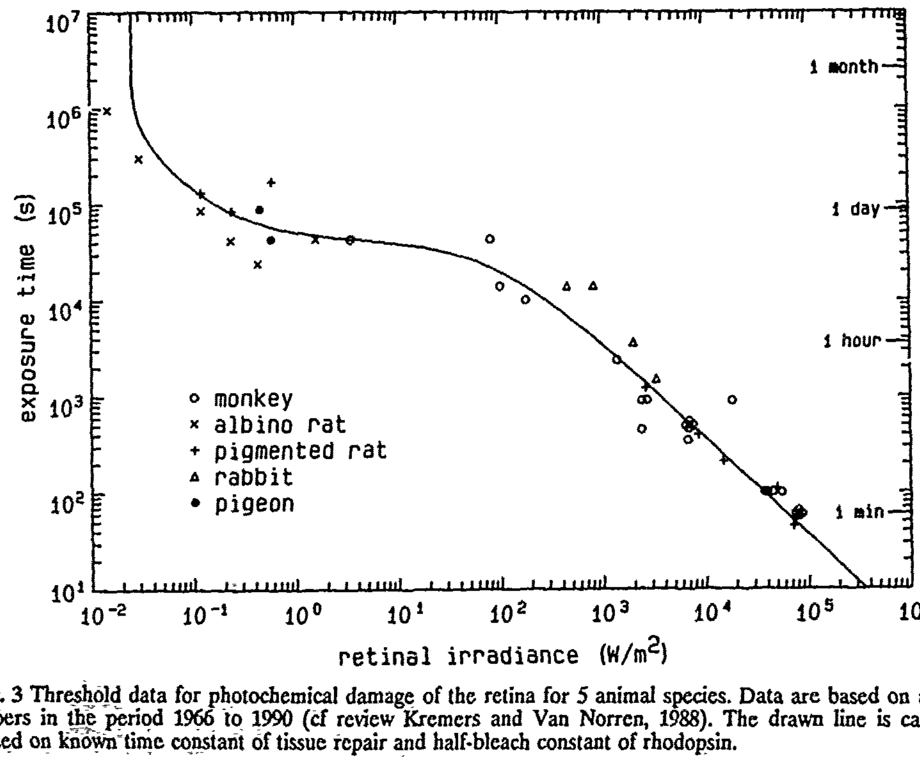

Fig. 3 Threshold data for photochemical damage of the retina for 5 animal species. Data are based on a dozen papers in the period 1966 to 1990 (cf review Kremers and Van Norren, 1988). The drawn line is calculated based on known time constant of tissue repair and half-bleach constant of rhodopsin.

Consequently, data in the upper left of the figure should be mediated by the visual pigment, and those at the lower right by another pigment. This can be checked by looking at action spectra.

ACTION SPECTRA

Data on action spectra are scarce. Noell et al. [4], in the first publication on retinal photochemical damage, concluded that in rats the action spectrum for damage strongly resembled the absorption spectrum of the visual pigment. His data, together with a more recent set [5] are reproduced in Fig. 4A.

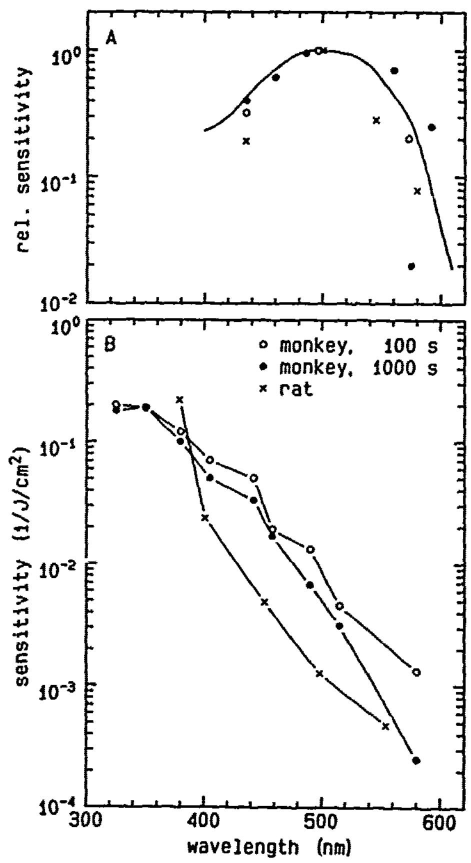

Fig. 4 Action spectra for photochemical damage of the retina. A: Literature data for albino rats after long exposures (sources: Noell et al., 1966; • Williams and Howell, 1981). Data fit the absorption spectrum of the visual pigment rhodopsin (drawn curve) B: Literature data (monkey, Ham et al., 1982; rat, Van Norren and Schellekens, 1990) pointing to a pigment with maximal sensitivity in the ultraviolet.

In these experiments exposure time was many hours. In 1982 Ham et al. [6] produced a totally different action spectrum in anesthetized monkeys, briefly exposed to small spots of very intense lights (Fig. 4B). It peaked in the ultraviolet.

An explanation of the different spectra in terms of difference in animals species has recently been invalidated. Van Norren and Schellekens [7] produced a monkey-like spectrum in rat by subjecting the animals to brief intense exposures. The identity of the pigment, or pigments, involved in the spectrum peaking in the UV is not known.

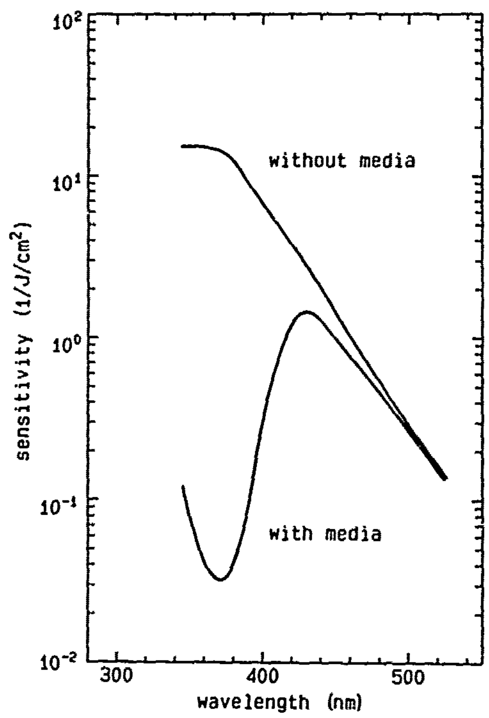

Fig. 5 Action spectrum for photochemical damage which high light levels, with and without absorption of the eye media, notably the crystalline lens.

One aspect of Ham's experiments deserves attention. To measure the spectrum over a wide wavelength range he had to remove the crystalline lens. It was mentioned before that the lens strongly absorbs near ultraviolet radiation (UV-A). In Fig. 5 the action spectrum for the more natural condition with the lens in place is shown. The spectrum peaks in the blue part of the spectrum, hence the term "blue light hazard" for this type of damage.

CONCLUSIONS

In the extensive literature on photochemical light damage, that on rats roaming for hours or days in illuminated cages, on the one hand, and that on monkeys briefly exposed to an intense spot of light, on the other hand, has led separated lives. It has, for instance, led to the notion that rats are far more vulnerable to light damage than monkeys. The model presented above unifies all data by suggesting that in all animals two classes of light damage exist, linked to two pigments. Which pigment is active, depends on the light level, because one is bleached in intense light. Differences in vulnerability between animal species are probably limited, at least at the retinal level.

What are the practical consequences of these insights? An important one is that the emphasis that has been placed on the hazard of blue and ultraviolet light is not justified for environmental light. The most sensitive photosensitizers in the retina are the visual pigments. Only when these are fully bleached, thus at extremely high light levels, the "blue light hazard" comes into view. Protecting ourselves against light damage mediated by the visual pigments, cannot be achieved with selective filtering of light. In bright environments we should, therefore, reduce the level, for instance, by wearing sun glasses or visors. This has long been common practice for reasons of comfort, but the argument of possible photochemical damage adds new emphasis. In addition, we should keep in mind that subthreshold damage might accumulate during life and promote senile macular degeneration.

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The Effects of Dazzle and Dazzle Generated Afterimages on Aiming and Tracking Performance

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Abstract

A series of experiments was designed to collect data for the modelling of aiming and tracking performance during and after dazzle exposure. Compensatory tracking performance was measured for static targets and targets moving with a constant linear velocity using a laboratory based tracking simulator. Tracking error was recorded with a bright non coherent dazzle source overlaid on the target and with target-dazzle separations of 0.5°, 1.0°, 2.0° and 3.0°. There was an indication that the dazzle source caused a significant deterioration in tracking performance. Tracking errors were inversely related to the separation between target and dazzle source and were at a maximum when target and dazzle were coincident.

The effects of dazzle may persist for a significant time after dazzle offset. Foveal afterimages measuring 1° were generated by brief exposure to an intense light source. Tracking error with an afterimage was recorded and compared to the errors recorded for normal foveal vision, and those arising when tracking using regions of the retir 2°, 4° and 6° peripheral to the fovea. A significant deterioration in tracking performance was evident with an afterimage. Comparable results were obtained when tracking using the peripheral retina at 4°-6°. This similarity is attributed to observers offsetting their gaze so as to image the target away from the non functioning foveal receptors. A significant learning effect was indicated.

Introduction

During compensatory tracking the operator manipulates a control with the objective of minimising some error signal, normally the distance between two stimuli, the position of one being under operator control. In aviation, tracking is a familiar behaviour, obvious examples being the alignment of the aircraft with particular geographical features (as in take-off and landing) and in the case of military operations the selection of targets for on-board missile systems.

Tracking places significant demands on both visual processing and on manual control performance. Environmental stressors which impair either of these modalities are likely to cause degradation in tracking. For instance manual control is directly impaired by vibration of the operator (McLeod and Griffin, 1986) an inevitable consequence of aircraft motion, or by a poorly implemented control law governing the response of the tracking system to operator input (Carver and Michael, 1978). Similarly, optimal tracking is dependent on the degree of visual acuity available to the observer and is therefore influenced by factors such as poor display contrast and glare (Luckeish and Moss, 1930).

Pilot vision may operate at less than optimal in a variety of circumstances. In addition to the possible impairment caused by solar glare from the canopy or poor instrument contrast mentioned above, a more serious threat to pilot vision may be p[illegible]d by laser weapons. A number of effects may be seen. A direct consequence of the incidence of laser radiation on the eye is termed veiling glare. This refers to a luminous veiling haze (or dazzle) which surrounds any bright light source and is likely to obscure objects imaged onto adjacent retinal receptors. This dazzle is derived from two principal sources : firstly, there is significant scatter of light within the tissues of the eye (Vos,1963; Vos and Boogaard, 1963; Vos and Bouman, 1964); secondly additional optical spread may be attributed to atmospheric effects. Whereas ocular spread is relatively quantifiable, atmospheric spread is more difficult to define as it is dependent on a large number of meteorological variables.

After the offset of a laser source, an observer is likely to experience some residual after-effects, the severity of which are related to the energy absorbed at the eye. At lower energy levels the observer is likely to experience a temporary elevation of contrast thresholds across the retina caused by the exposure of the eye to an intensity of illumination far in excess of that to which it is currently adapted. This is often referred to as flash-blindness (a term originally derived from atomic flash tests), and recovery is dependent on adaptation state and the intensity of the incident light. The effects are however likely to persist for a significant time after exposure. Miller (1966) demonstrated a sustained effect for up to 100 seconds.

Higher energies of incident radiation may cause actual retinal damage. A typical result of such exposure is the formation of an additional blind spot or scotoma within the irradiated area. The likelihood of recovery from such damage is related to the mechanism by which it was caused. For instance physical damage to the surface of the retina caused by the heating effect of light near the infra-red is likely to be permanent, whereas there exists a good chance of recovery from photochemical damage caused by light near the blue end of the spectrum. Recovery in either case occurs over a long timescale, and the scotomata created are likely to interfere with visual processes for a considerable period.

The location of a scotoma is important in determining the loss of visual function. Scotomata in the peripheral retina may cause little disruption and may go unnoticed in all but, for instance, search tasks. A foveal scotoma on the other hand is likely to cause severe visual impairment (See Sliney and Wolbarsht, 1985, Chapter 4 for a review of laser induced ocular damage). In addition it is hypothesised that although the fovea covers only a small proportion of the surface of the retina, there exists a high probability of a foveal scotoma due to the likelihood of an observer foveating any bright object entering the field of view.

Laser weapons are therefore likely to cause two types of visual disruption. Firstly, during laser exposure the observer is dazzled and immediately after exposure experiences a degree of flashblindness which has a similar effect to dazzle and decays with time. Secondly in certain configurations a laser may cause ocular damage, forming additional blind spots (or scotomata) on the retina. The blink reflex is designed to protect the eye from exposure to potentially hazardous light energies but occurs over approximately 0.25 sec and may therefore be too slow to prevent damage by intense laser radiation.

The effects of a foveal scotoma on tracking performance have been researched by Burbeck and Boman (1989). They measured tracking errors for a randomly moving 0.5° target with simulated 1.0° and 2.8° scotomata centred on the fovea (Diameter of foveola = 1.4°, Polyak, 1941). They found that performance improved rapidly over three daily sessions and attributed this to observers learning to offset their gazes so that tracking could occur using vision peripheral to the fovea. They reasoned that this technique of 'looking where the target isn't' was unnatural, hence the substantial learning effect. They found that at all times tracking was significantly impaired by a scotoma, recording a mean tracking error of 0.64° with a 2.8° scotoma and 0.43° with a 1° scotoma, compared to 0.28° in the control condition. Their measurements of eye movements indicated that subjects not only offset their gaze sufficiently to make the target visible beyond the scotoma, but also maintained a clear separation of 1° or more between scotoma perimeter and target.

The research reported here investigates the effects of both dazzle and scotomata on tracking performance. It was hoped to confirm the findings of Burbeck and Boman (1989) in addition to providing data more suited to modelling (for inclusion in the British Aerospace Oracle Vision Model) by restricting targets to constant linear velocities. In addition it was planned to assess the dependence of tracking errors on the offset between a dazzle source and target.

The Effects of Dazzle on Tracking Performance

Method

The design of a tracking system interface has a profound influence over operator performance with that system. For example, performance depends on the error feedback (Hill, 1970), tracking system gain (Gibbs, 1962) and even the direction in which the control operates relative to the midline of the body (Corrigan and Brogden, 1949). Since each tracking system has its own characteristics, a simplified laboratory based tracking system was devised for this research so as to maximise the generality of the findings.

The tracking system comprised a Measurement Systems 446-G525 joystick interfaced to an IBM-PS/2 through a Data Translation DT2801 analogue to digital converter. Subjects sat in a darkened room with an eyepatch over the left eye. Target and cursor were displayed on a long persistence monitor (Green P43 phosphor) viewed from 1 metre at a luminance of 1.26 cd/m^2 against a background of 0.3 cd/m^2 (contrast=3.2). All tracking was compensatory, meaning that it was the task of the observer to overlay a moving target on the centre of a pair of stationary cross-hairs.

A single fully trained subject participated in the experiment. Using the thumbstick mounted on the joystick the observer was required to track a circular target 0.5° in diameter, which was moving linearly with angular velocities of 0, 1, 2 and 3°/s using a full screen (12.0° × 4.9°) cursor. A half silvered mirror was placed between the monitor and the observer. A bright non-coherent light source was passed through a pinhole (90 seconds arc in diameter) and reflected in this mirror so as to be offset from the target by 0.0°, 0.5°, 1.0°, 2.0° or 3.0°. Calibration of the dazzle source was difficult due to the high intensity and small area of the light transmitted through the pinhole. The maximum luminance at the centre of the dazzle was approximately 20,000 cd/m² and caused total obscuration of the screen over an area of approximately 1° in diameter with reduction in contrast considerably beyond this. A non-coherent source was favoured to a coherent source primarily for safety reasons. Also it is suggested that over ranges of the order of a couple of kilometres the coherence of a laser may be disrupted by effects such as atmospheric turbulence (see Sliney and Wolbarsht, Chapter 13). Such being the case, a non coherent light source may actually provide a more realistic simulation over short ranges.

Tracking error was sampled at 10 Hz during ten 10 second trials for the four target velocities without dazzle and in each of 20 combinations of target velocity and dazzle offset. Pilot studies suggested that steady state tracking was not attained until the 6th second of each tracking run, therefore the mean tracking error was calculated over the last 4 seconds of each 10 second trial. The target initially appeared at one of six locations 4° offset from the cursor which was positioned at the centre of the monitor. Irrespective of target location, initial target trajectory was directly towards the cursor.

Results and Discussion

Table 1 and Figure 1 show the mean tracking error recorded in each experimental condition. From Figure 1 it is evident that tracking errors were inversely related to the separation between target and dazzle source. Table 2 and Figure 2 show the same data averaged and replotted as a ratio of error scores in dazzle and no-dazzle conditions. Tracking errors were at a maximum when dazzle and target were coincident, averaging nearly four times those occurring without dazzle. This confounds the notion that in this situation the dazzle itself might act as a useful aim point. Increases in tracking error were evident for target dazzle offsets of 2° and 3°. Although target and cursor were visible through the dazzle halo in this instance the reduced contrast has clearly impaired tracking.

Dazzle Offset	Target Velocity							
	Static		1°/sec		2°/sec		3°/sec	
	Error	SE	Error	SE	Error	SE	Error	SE
No Dazzle	0.018	0.009	0.064	0.024	0.076	0.026	0.091	0.020
0 °	0.136	0.073	0.185	0.087	0.182	0.041	0.224	0.068
0.5 °	0.128	0.049	0.118	0.037	0.151	0.045	0.141	0.033
1.0°	0.072	0.053	0.101	0.052	0.105	0.033	0.144	0.046
2.0 °	0.0	0.012	0.076	0.033	0.095	0.021	0.098	0.037
3.0°	0.041	0.015	0.070	0.012	0.073	0.022	0.107	0.026

Table 1 : Mean tracking error and standard error for target velocities of 0°/s, 1°/s, 2°/sand 3°/s, without dazzle and with dazzle target separations of 0°, 0.5°, 1.0°, 2.0° and 3.0 °.

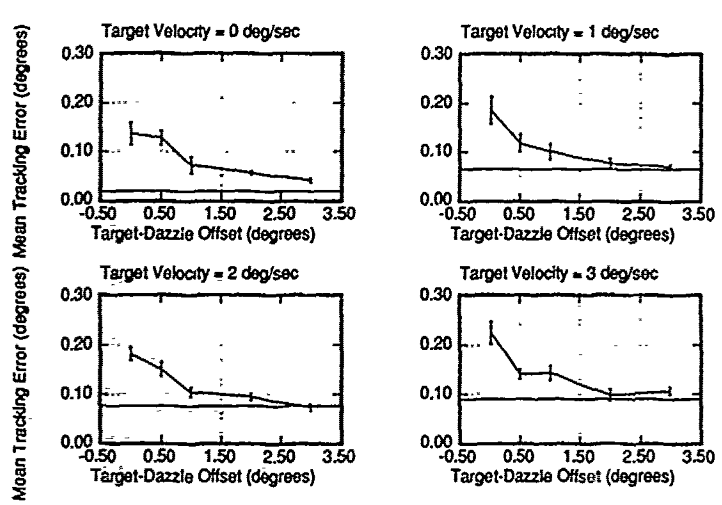

Figure 1 : Plot of the results shown in Table 1. Mean tracking error and standard error for target velocities of 0°/s, 1°/s, 2 °/s and 3°/s, without dazzle and with dazzle-target separations of 0°, 0.5°, 1.0°, 2.0° and 3.0 °. Horizontal lines indicate the mean tracking error without dazzle in each condition.

Target-Dazzle Offset	Mean Tracking Error / Mean Tracking Error Without Dazzle
0.0°	3.81 ± 1.66
0.5°	3.07 ± 1.04
1.0°	2.11 ± 1.16
2.0°	1.64 ± 0.47
3.0°	1.35 ± 0.39

Table 2 : Mean Tracking Error (and standard error) expressed as a ratio of that recorded with dazzle to that recorded without dazzle. These results are the average taken over all four target velocities.

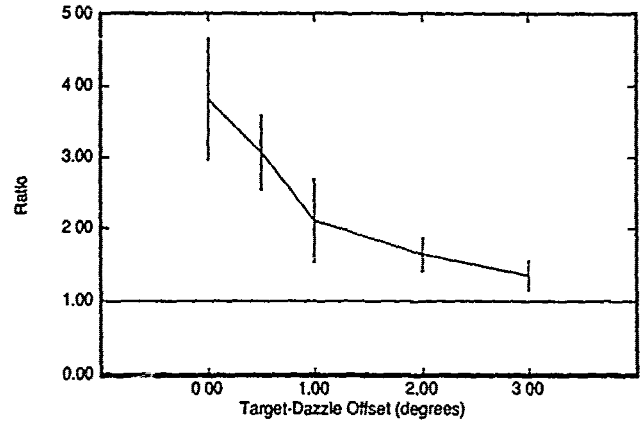

Figure 2 : Plot of the Results Shown in Table 2. Mean Tracking Error expressed as a ratio of that recorded with dazzle to that recorded without dazzle. These results are the average taken over all four target velocities.

The Effects of a Foveal Scotoma on Tracking Performance

Method

For the scotoma work the same tracking system was used as for the dazzle work described previously except that the target and background luminances were increased to 10.7 and 3.0 cd/m^2 respectively giving a contrast of 2.57. As before mean tracking errors for each experimental condition were calculated from measurements (made at 10 Hz) of the tracking error for the last 4 seconds of ten 10 second trials.

Burbeck and Boman (1989) generated foveal scotomata by monitoring eye movements, and blanking in real time the area of the screen being foveated. This represents a considerable technical achievement and it is attractive in terms of the precise method in which the scotoma can be controlled. A more realistic simulation of an actual laser strike on the eye may be obtained, however, by exposing subjects to a bright stimulus producing an afterimage that persists for the duration of each experimental trial. It was this option that was selected for this experimental work.

Scotomata were simulated by exposing subjects monocularly to a 200 msec 10^{6}cd/m^2 flash from an aperture measuring 1° in diameter. Precise alignment of the eye and stimulus prior to each exposure (using a headrest and the parallax effects of two pairs of crosswires) ensured that scotomata were centred on the fovea. Due to optical spread the scotomata actually generated were slightly larger than the size of the target, being measured as having an effective mean diameter of 1.3°. The persistence of the afterimage was the ultimate factor in limiting the duration of each trial since opacity could only be guaranteed for the order of 10 seconds.

Six subjects participated in the experiment. It was intended that the experimental scenario would resemble an operational setting as closely as possible. Therefore subjects were fully trained in the tracking task but had no previous experience of tracking with a scotoma. Over four randomised daily sessions tracking errors were measured for linear target velocities of 0, 1, 2 and 3°/s with and without a scotoma. In addition, by placing a fixation cross on the monitor, tracking errors were recorded for tracking using the peripheral retina at 2°, 4° and 6°.

Results and Discussion

Figure 3 shows the mean tracking error over the 10 second duration of each 10 second trial. These data are averaged across all subjects for each experimental condition. The tracking error of 4° at the commencement of each trial corresponds to the initial offset between target and cursor. There is a indication of a lengthy acquisition period lasting approximately 6 seconds followed by 4 seconds steady state tracking. There is a clear differentiation between tracking performance at each retinal location for the unimpaired eye. As would be predicted the lowest error scores were recorded for foveal tracking with a systematic deterioration in performance with increasing viewing eccentricity. A foveal scotoma caused a significant decrement in performance. There is an indication that in this case tracking performance equated to that which occurred when viewing approximately 6° peripheral to the fovea. Such a finding is consistent with the conclusions of Burbeck and Boman (1989), namely that subjects tended to offset their gaze so as to image the target and cursor on retinal receptors peripheral to the scotoma. Indeed all subjects reported having spontaneously adopted this strategy in the early stages of the experimentation. The indicated gaze offset of up to 6° is, however, rather larger than would be expected. With a 1.3° foveal scotoma and a 0.5° target the observer would need to offset her/his gaze by 0.9° ((scotoma size)/2 + (target size)/2) in order to make the entire target visible. Burbeck and Boman (1989) demonstrated from actual eye position recordings that subjects prefer to maintain a clear separation of 1° between scotoma and target from which it might be expected that a total offset of roughly 2° would be recorded, considerably lower than the 6° offset that has been suggested.

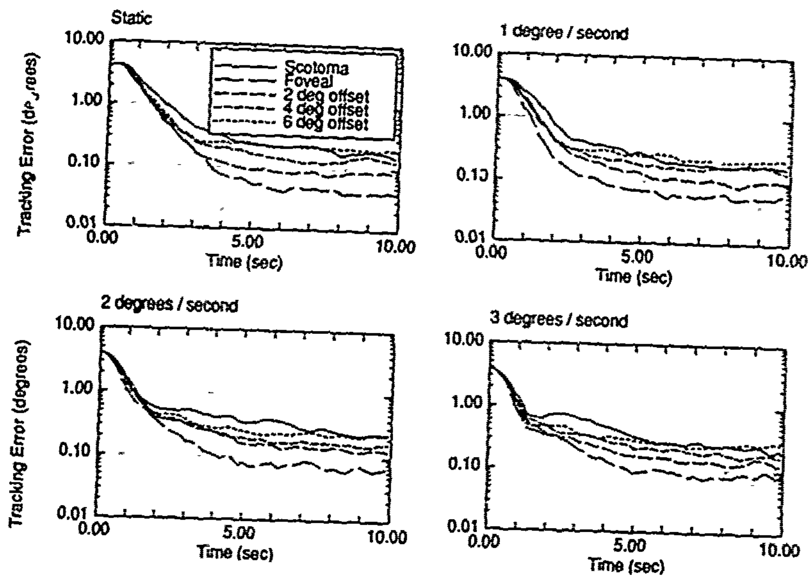

Figure 3 : Mean tracking error (n=6) over the 10 seconds duration of each tracking trial. Results are shown for each of the four target velocities (0°/s, 1°/s, 2°/s and 3 °/s) and for each of the five viewing conditions (Foveal, with offsets of 2°, 4° and 6° and with a foveal scotoma).

Viewing Condition	Target Velocity (°/s)							
	0		1		2		3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Scotoma	0.117	0.055	0.105	0.053	0.152	0.084	0.138	0.060
Foveal	0.025	0.009	0.032	0.004	0.040	0.009	0.048	0.005
2° offset	0.048	0.015	0.053	0.007	0.080	0.034	0.077	0.015
4° offset	0.075	0.019	0.092	0.018	0.095	0.010	0.103	0.022
6° offset	0.120	0.023	0.125	0.026	0.138	0.031	0.150	0.014

Table 3 : Mean R.M.S. tracking error and standard deviation (degrees) recorded with a foveal scotoma, with normal foveal vision and viewing peripherally at 2°, 4° and 6°. Target velocities were 0°/s, 1°/s, 2°/s and 3 °/s.

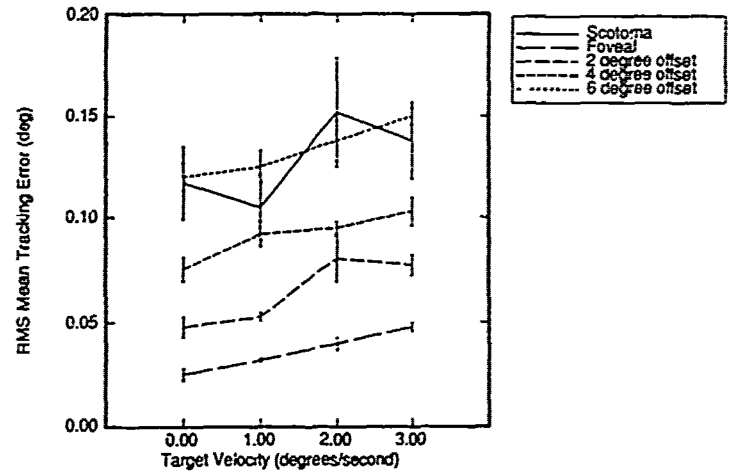

Figure 4 : Mean R.M.S. tracking error and standard deviation (degrees) recorded with a foveal scotoma, with normal foveal vision and viewing peripherally at 2°, 4° and 6°. Target velocities were 0°/s, 1°/s, 2°/s and 3 °/s.

Table 3 and Figure 4 show the mean tracking error averaged over six subjects for each of the 20 experimental conditions. There is a clear indication that tracking errors increased both with increased target velocity and increased viewing eccentricity and were elevated by a foveal scotoma. As before there is an indication of some similarity in the results for the scotoma condition and those obtained when viewing 6° peripheral to the retina, lending support to the notion that subjects offset their gaze by as much as 6° in order to make the target visible. There is however a higher variability in the scotoma condition (see standard deviation scores in Table 3). Table 4 shows the mean tracking error across all subjects and all target velocities over the four daily experimental sessions. There is a clear learning effect across scotoma trials. Mean tracking errors with a scotoma improved from 0.281° on the first day to 0.178° on the fourth day, a more dramatic improvement

	Day 1	Day 2	Day 3	Day 4
With scotoma	0.281	0.225	0.221	0.178
No scotoma	0.156	0.139	0.127	0.150

Table 4 : Mean tracking error (degrees) over all target velocities and viewing conditions for each of the four experimental sessions.

than that seen for non-scotoma trials. This effect presumably contributed to the higher variability in tracking errors recorded with a scotoma. The poor performance recorded during early scotoma trials was perhaps due to observers attempting to foveate the target. It was only after some practice that observers adopted the gaze-offset strategy and this may have given rise to the dramatic improvement in performance for scotoma trials seen by the second day. There is a strong possibility that as simple a measure as prompting naive subjects to adopt the gaze offset strategy would have been of benefit in early scotoma trials. The poor performance of subjects in initial encounters with a scotoma has certainly contributed to the overall elevation of mean tracking errors in the scotoma condition. Therefore the actual gaze offset achieved by the observers on the fourth day of experimentation may have been considerably lower than the 6° offset which was indicated by Figures 3 and 4.

Conclusions

It has been demonstrated that a dazzle source may cause a significant decrement in tracking performance via two mechanisms. During irradiation dazzle effects may hinder target acquisition and tracking. The precise degree of impairment is likely to be a function of the intensity of the dazzle source, the proximity of the dazzle source to the target, and the contrast of the target. In the configuration used in the present study maximum interference to tracking occurred when target and dazzle were coincident. A significant impairment to tracking was evident for target-dazzle offsets of 2° and 3° even though the target was visible through the dazzle halo at this offset.

It must be pointed out that the non-coherent dazzle source which was used for the experimental work described above differed from coherent light source operated in the field in two important respects : firstly, a coherent light source is subject to significant interference effects giving a fine grained speckled impression at the eye. This irregular speckling may cause a significantly increased impairment to target visibility. Secondly the dazzle source which was used in this experimental work was viewed from 1 metre and was therefore not subject to any significant atmospheric effects. Viewed through as little as a couple of hundred metres of atmosphere, a bright light source is subject to refractive effects. Although dependent on meteorological conditions, such effects typically cause fluctuation of the dazzle halo with time, giving periods of relatively high target visibility. An experienced observer will learn to reacquire the target and track accurately during these momentary lulls. As a final point, the observers in this experiment were forewarned of the dazzle source and were aware that it was eye safe. Little or no startle effects were therefore involved. In the field the rational response to the sudden onset of a laser source may be to close the eyes so as to shield them from possible damage, clearly causing significantly greater disruption to tracking than may have been revealed by this study.

It has been demonstrated that tracking performance is likely to be impaired after the offset of a laser or other bright light source. A 1.3° scotoma on the fovea caused an elevation in mean tracking errors to 355% of those recorded with unimpaired vision. The performance of naive observers seemed particularly susceptible. Tracking errors recorded during the first scotoma trials gave rise to mean tracking errors at a level of 441% of those recorded for unimpaired vision, compared to 279% for the last (fourth) scotoma trials. This learning occurred over a relatively short time (subjects tracked with a scotoma for a total of 6.7 minutes over the four days of the experiment). A major contribution to this effect may have been the adoption of the gaze-offset strategy by the observers and their subsequent refinement of this technique. Burbeck and Boman (1989) demonstrated an increased proficiency for this technique with practice. This is not wholly unexpected since in normal circumstances the viewing of a target with the periphery (i.e. looking where the target isn't) is highly irregular and foveation is compulsive.

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Acknowledgements

This work was carried out with the support of Procurement Executive Ministry of Defence

USE OF CONTACT LENSES (CL) BY AIRCREW IN THE USAF, A PROGRESS REPORT

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SUMMARY

In June, 1989, the Chief of Staff, USAF, approved a plan authorizing, for the first time, the use of corrective CL in flight by aircrews of the USAF. Eligible aircrew under this plan include all those requiring distant vision correction and having less than 2 diopters astigmatism. There is a recognized operational advantage to the use of CL vice spectacles in several Air Force missions. These include, most notably, the operation of high performance aircraft, and/or the use of night vision goggles to accomplish the mission. Therefore, the use of CL in flight is now optional for all physically qualified aircrew in the USAF. Prior to initiation of this program, a thorough literature search was accomplished. Based on data from studies on the complications associated with CL, the loss of 70 flying days per 1000 CL wearing aviators and four permanent groundings per 10,000 CL-wearing aviators per year were predicted from CL-related problems. Safety of flight in high performance aircraft with CL was determined by a 1-year study of 89 aviators in Tactical Air Command, completed in 1989.(2) Complication rates were very close to those predicted. In order to further validate predictions, or rapidly detect any negative trends, the implementation plan includes a requirement for close professional follow-up of all CL-wearing aviators. Detailed quarterly reports on total number of CL-wearing aircrew, CL-related medical groundings, safety incidents, etc., are required by the Surgeon General, USAF.

So far, there have been no permanent groundings nor CL-related safety incidents. After 856 aircrew-years of CL use, the rate of temporary grounding remains close to early predictions.

BACKGROUND

The need to use corrective lenses has long been the bane of a pilot's existence, especially for pilots of high performance aircraft. Spectacles obviously do not make safe flight impossible, they merely provide another distraction and potential complication to overcome while attending to the demanding tasks of operational aviation. Spectacles are frequently incompatible with life support equipment such as helmets, masks, and visors. When in a high G environment, glasses often slide down on the aviator's nose, limiting the area of corrected vision. Under Gs, or at other times, the oxygen mask may develop a leak along the upper edges, which, in turn, causes fogging of the lenses. The spectacle frames, no matter how well designed, create "blind spots" in the aviator's field of view. During the descent phase of an instrument approach, spectacles often fog because of the temperature and humidity changes. When a bespectacled fighter pilot is "checking six," he inevitably reaches a point at which he is looking beyond the edge of the lens and, thus, no longer has corrected vision.

Even if selection procedures are designed to choose pilot candidates who do not require corrective lenses, the natural ocular aging process will require most aviators over 40 years old to wear them. Thus, there will always be aviators who require visual correction. The realities of the current selection process require us to train some pilots who already need spectacles. A much greater proportion of newly trained navigators require visual correction. Approximately 10% of undergraduate pilot training students and one-fourth of navigator students must wear glasses. These percentages increase dramatically over the average career. A recent survey of all active USAF aviators revealed that over 27% of pilots and nearly 51% of navigators wear corrective lenses to fly.

For many years, there have been efforts to find a better means than spectacles to safely correct the aviator's vision. Each time technology has provided a new method to correct vision, the new technique has been thoroughly examined for its applicability to aviation. Many of these techniques have been approved for use in civilian aviation, but have not been adopted by the military. The demands of military aviation, especially in the high performance arena, are much less forgiving of temporary incapacitation, distraction, or substandard vision, than those of private or commercial flying.

One of the most popular alternatives to spectacles is contact lenses. They are, however, fraught with multiple problems which were, until recent technological advances, incompatible with military aviation. They have, however, been changed and improved dramatically over the last several years. Each time a new material or design has emerged, new rounds of evaluation for compatibility with military aviation have ensued. Until recently, unacceptable risks of temporary distraction or incapacitation associated with available types of contact lenses have lead to disapproval. Major concerns exist in two areas. First, would the contact lenses be likely to cause problems that would impact flying safety or operational effectiveness? This concern involves the possibility of lenses compromising visual acuity or causing distraction due to displacement or foreign objects under the lens. Second, would the use of contact lenses cause an unacceptable loss of valuable aviator resources, through temporary groundings for minor problems, or through medical disqualification for permanent reduction in visual acuity secondary to contact lens wear? Temporary groundings could be caused by severe red eye reaction, including severe keratitis or conjunctivitis presumed not to be infectious in nature. Corneal infections which clear completely would also cause only temporary grounding. Any infection which resulted in corneal scarring in the visual axis and subsequent permanent reduction of visual acuity below 20/20 (corrected) would cause permanent disqualification of the affected air crew member.

New materials and designs of soft contact lenses have resulted in lenses which are less prone to easy dislodgement or to significant displacement with G forces. Also, with these lenses, there are fewer problems with small particles getting trapped under the lens, causing distracting foreign object sensation, than with the older rigid contacts. Testing of these lenses, including centrifuge testing, showed relatively few complications. Experience with these lenses on the civilian market provided relative reassurance as to the low frequency and generally mild severity of contact lens related ophthalmologic problems. Thus, the decision was made to operationally test them in Air Force aviators.

In 1987, a six-year study of civilians wearing soft contact lenses was published in the Journal of the American Optometric Association.(1) This study followed over 200,000 individuals wearing soft contact lenses, either on a daily wear (remove and clean every night and replace every morning), or an extended wear (worn continuously for over 24 hours) basis. The investigators documented the number and types of ophthalmologic complications associated with each wear schedule. The results of this study showed a seven-fold increase in corneal infection, and a four-fold increase in individuals experiencing permanent reduction of visual acuity, when contacts were worn on an extended vice a daily wear basis. This solidified the position of Air Force eye care specialists that, if the Air Force were to allow military aviators to wear contact lenses while flying, they should wear only soft contacts, and only on a daily wear basis.

Extrapolation of the complication rates documented by the above study to the Air Force flying population led to an estimate of 270 days of temporary groundings per year for every 1,000 aviators wearing contact lenses on an <u>extended</u> wear basis. By requiring only <u>daily</u> wear usage of soft contact lenses, that rate was predicted to drop to 70 grounding days per year per 1,000 contact lens wearing aviators. Likewise, predictions were that we would lose 1 aviator to permanent grounding per year per 1,000 contact lens wearers if extended wear were allowed. Requiring only daily wear usage, however, would drop that number to 0.4 per year.

STUDIES

Based on a willingness to accept these loss rates in order to achieve the potential operational advantage afforded by contact lens wear over spectacles, a one-year Air Force test program was initiated to determine the effectiveness and safety of wearing these lenses in operation tactical aircraft.(2) This special project, conducted with the cooperative management by the USAF School of Aerospace Medicine and the USAF Tactical Warfare Center, was actually the final phase of a seven phase study on the feasibility of soft contact lens wear in the aerospace environment, begun at the USAF School of Aerospace Medicine in 1982. The phases of the program were as follows:

1. Acceleration (+Gz effects)
2. High altitude exposure
3. Rapid decompression effects
4. Altitude and low humidity effects
5. Chemical warfare agent effects
6. Multiplace aircraft study
7. High performance aircraft study

The results of the first six studies were encouraging, and suggested that soft contact lenses could be tolerated in the aerospace environment. In order to minimize the likelihood of injury to aviator's eyes and the risk to flying safety, the high performance aircraft study was designed to be particularly conservative. Soft contact lenses approved for extended wear were worn on a daily wear basis by the 82 participating crew members. Cleaning solutions were carefully chosen to minimize reactions.

During this study, a representative sample of pilots and weapons system operators in F-111, F-4, F/RF-4, F-15, and F-16 aircraft compared contact lenses to spectacles in a number of areas. These included task performance, compatibility with flight equipment, wearability, supportability, maintainability, and operational acceptability. Medical acceptability was assessed by designated eye care specialists. Effectiveness was based on subjective assessment by the aircrew as to ease of visual task performance wearing contact lenses compared with spectacles.

RESULTS

81 of the 82 aircrew members participating in the study (98.7%) rated contact lenses as better or the same as spectacles for performing visual tasks associated with tactical air missions. Likewise, in the overall assessment, 81 of 82 (98.7%) preferred contact lenses to spectacles.

Medical results of this study showed the complication rate for temporary disqualification (75 days per 1,000 aviator years) to be roughly equivalent to the civilian rate, and there were no permanent groundings during the one year study. The only difficulty encountered was supportability in local optometry clinics. This is a site-specific problem, but is representative of many of the bases that would fit and dispense contact lenses. The actual impact of contact lens care on optometric resources is uncertain, but it will undoubtedly have some effect on the availability of these services for other beneficiaries.

The results of the study were strongly supportive of the use of contact lenses by USAF aircrew. The numbers do not, however, reveal one of the strongest points...that of overall aircrew enthusiasm. The aviators' written assessments frequently contained comments like "Excellent peripheral vision. Visuals on traffic at 3 and 9 o'clock were much more frequent"; "Greatly improved ability for night flying by reducing reflection of cockpit lights."; "Contacts give me a tactical advantage in the air."; etc. This, combined with the lack of significant problems during the study, led to the decision to proceed with an implementation plan for general use of contact lenses by USAF aviators. This plan was implemented by approval of the USAF Chief of Staff on 21 Jun 1989.

IMPLEMENTATION PLAN

Based on this plan, contact lenses are made an option for use by all USAF aircrews who meet the following prerequisites.

1. Require corrective lenses to achieve 20/20 visual acuity.

2. Require correction for distant vision only.

3. Have corneal astigmatism not exceeding 2.0 diopters.

4. Corneas must exhibit clear and regular keratometry readings.

5. Be able to achieve visual acuity of 20/20 or better in each eye with contact lenses and with spectacles immediately after removing the contact lenses.

6. Have no history of significant ocular, periocular, or medical diseases that contraindicate contact lens wear.

Aircrew who elect to use contact lenses must keep a pair of clear prescription spectacles in an immediately available location while flying. Should any problems arise with the contact lenses during flight, the aircrew must be able to rapidly and safely discard them and put on the spectacles.

Contact lenses dispensed to USAF aircrew must meet the following standards.

1. Water content must not exceed 55 percent.

2. Lenses may not be tinted.

3. Only those lenses and solution specifically approved by the ophthalmology section of the USAF School of Aerospace Medicine may be used.

Wear of the lenses must comply with the following guidelines:

1. Wear is optional. Contact lenses must be removed any time they are uncomfortable.

2. Aircrew must wear contact lenses only while awake. They must not be worn for over 24 hours at a time.

3. Should any ocular problem occur, they must remove the contact lens immediately, resume spectacle wear, and contact their flight surgeon.

4. They may not participate in any mission which requires using contact lenses to complete the mission safely.

In order to assure rapid detection of individual or general population contact lens related problems, a regular follow-up schedule is mandated and a rapid reporting system to the USAF Surgeon General is in place. Aircrew who do not comply with the designated follow-up schedule are administratively grounded until their follow-ups are current.

CURRENT STATUS

Now, one year since the approval of the USAF Contact Lens Implementation Plan, 1,850 Air Force personnel are wearing contact lenses while performing aviation duties. This includes 474 new wearers in the past three months. 66% of aviators wearing contact lenses fly in high performance aircraft. There have been no permanent medical groundings as the result of contact lens wear. However, this is not inconsistent since projections based on civilian studies would only predict 0.34 permanent groundings at this point. Data concerning temporary groundings is summarized in the following table.

Quarter	1	2	3	4	Total
Wearers	386	704	1376	1850	(856 wearer/years)
#DNIF*	2	5	6	16	29
(Med)	2	4	4	11	21
(Admin)	0	1	2	5	8
Days DNIF	20	46	63	80	209
(Med)	20	16	20	33	89
(Admin)	0	30	43	47	120

*Duty Not Including Flying

By disregarding the administrative groundings (missed follow-up exam, etc.), the calculated DNIF rate for medical causes is 104 days/1000 contact lens wearing aviators/year. This is surpricingly close to the rate of 70 days/1000 contact lens wearing aviators/year projected prior to implementation of the program. Most importantly, there have been no safety incidents or mishaps attributed to contact lens wear.

Aviator enthusiasm about the program remains particularly high, and we have every reason to be pleased with the program's success.

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CONTACT LENSES IN THE U.S. ARMY ATTACK HELICOPTER ENVIRONMENT

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Abstract Introduction

Recent technological advances have had a major impact on military aviation. While modern methods of providing visual information via electro-optics/visionics systems have extended the aviator's operational envelope, these devices are becoming increasingly incompatible with spectacle wear. Since approximately 20 percent of Army aviators are ametropic (spectacle wearing), alternative means of providing a refractive error correction need to be investigated. One alternative being considered is the use of a contact lens correction.

Abstract Methods and Results

For the past year, the U.S. Army Aeromedical Research Laboratory (USAARL) has been conducting a worldwide, AH-64 "Apache" contact lens research project in order to develop a comprehensive database on contact lens wear in a variety of environments. A three-tier contact lens fitting system is being used: two different types of soft lenses and one rigid gas permeable (RGP) lens type. The wearing schedule is set at a maximum of 7 days/6 nights of extended lens wear. Fundamental operational data is being chronicled by unit flight surgeons. Standard clinical data is being used in on-going command deliberations on future medical policy decisions concerning contact lens wear by Army aviators. Basic research information is being gathered in an effort to determine the fundamental physiological response of the cornea to the presence of a contact lens. Up-to-date results are presented as an introduction to interactive discussions.

Abstract Conclusions

The subjective assessment of contact lens applications within the aviation community is universal acceptance. While current clinical data indicate some ocular health risk, flight safety risks are minimal. Establishment of long-term contact lens efficacy likely will depend on the ensuing analysis of physiological data.

INTRODUCTION

Recent technological advances have had a major impact on Army aviation. While modern methods of providing visual information via electro-optics/visionics systems have extended the aviator's operational envelope, these devices are becoming increasingly incompatible with spectacle wear. Specifically, standard refractive error correction options for the M-43 protective mask have proven to be incompatible with the Helmet Display Unit (HDU) component of the AH-64 "Apache" Integrated Helmet and Display Sighting System (IHADSS). Glue-on and outsert packages push the HDU, a Maxwellian-view virtual imaging system, far enough from the ametropic aviator's eye to significantly reduce the available field-of-view; consequently, peripheral instrumentation and weapon system overlays cannot adequately be visualized. One alternative to spectacle wear being considered is the utilization of a contact lens correction.

Current Army Regulations prohibit the wearing of contact lenses by aviators while flying. Waivers to these regulations have been approved for volunteer subjects under the aegis of a controlled scientific investigation. Consequently, the U.S. Army Aeromedical Research Laboratory (USAARL) has initiated an Army-wide AH-64 contact lens research protocol in order to provide both an interim readiness fix and to develop a comprehensive database on contact lens wear in a variety of environments. Basically, the protocol has been organized from three different perspectives with concerns directed toward operational and flight safety issues, ocular health issues and their secondary effects on existing health-care delivery systems, and potential for long-term changes in corneal physiological integrity.

A standardized fitting and data collection protocol was established; specific baseline evaluations, in addition to standard clinical appraisals, included: Endothelial morphological assessments, anterior lens surface pH recording, trans-lens oxygen uptake rate monitoring, and tear film osmolarity determinations. This basic research information is being gathered in an effort to determine the fundamental physiological response of the cornea to the presence of a contact lens. The clinical data will be of value as a reference for command deliberations on future medical policy decisions concerning contact lens wear by Army aviators. Fundamental operational data is being chronicled by specially trained unit flight surgeons in order to document the impact of routine contact lens wear on relevant aviation medicine issues. During that time it is anticipated that sufficient data will be obtained to provide the basis for an informed decision concerning overall Army policies regarding extended wear contact lenses.

METHODS AND MATERIALS

Two civilian contract optometrists and one technician are responsible for the provision of contact lens fitting and follow up examinations. Volunteer subjects from AH-64 units, and units fielded with the M-43 protective mask were provided with informed consent and an individual formal waiver to participate in the study. The 2-year study period will cover 200 subjects at 9 different Continental United States (CONUS) locations, plus 5 Federal Republic of Germany (FRG) locations.

The study is scheduled to conclude at the end of September 1991. A three-tier contact lens fitting system was utilized, with the initial lens of choice being a moderate to high water content disposable extended wear soft lens. Backup lenses consisted of a low water content standard extended wear soft lens utilized on a disposable basis, and a rigid gas permeable (RGP) lens used with a chemical disinfection system. All three types of lenses were approved by the United States Food and Drug Administration (USFDA) for routine use.

The wearing schedule was set at a maximum of 7 days/6 nights of extended lens wear, in accordance with USFDA recommendations. The subjects were instructed that the 7th night was to be passed without lens wear; worn soft lenses were to be discarded, and RGP lenses cleaned, disinfected, and stored overnight. After at least one full night of lens-free sleep, the subjects were instructed that they could apply a new soft lens, or resume wear of the cleaned and disinfected RGP lenses. This pattern of wear and rest was to be continued until the next scheduled quarterly follow up evaluation.

Each quarterly follow-up examination adhered to the same testing protocol established for initial examinations. An additional component to each quarterly follow-up was the inclusion of a subjective questionnaire to query apparent effectiveness of contact lens wear in job performance. Generalized background information concerning flight hours and conditions are also documented for future safety issue reference.

RESULTS AND DISCUSSION

To date, 223 volunteer subjects have been examined for possible contact lens wear: 31 subjects were not able to be fit with lenses, and 19 subjects had to be discontinued or withdrawn from the study after an initially successful contact lens fit. Therefore, although 86 percent of the volunteer subjects were successfully fitted with contact lenses, only 77 percent have been successful in wearing the lenses. Average length of time in the program is ten months, with a range of 1 to 20 months.

The two areas of greatest difficulty involved those individuals dependent upon a near or reading correction (presbyopic) in the cockpit, and those exhibiting high amounts of ocular curvature distortion (astigmatism). Presbyopic subjects were not routinely fitted with lenses, since a reading overcorrection would defeat the purpose of contact lens wear in lieu of spectacles. Highly astigmatic subjects were not able to obtain adequate visual acuity with soft lenses; RGP lenses were demanding to fit and difficult to adapt to. As a result few subjects are successfully wearing RGP lenses.

Average wearing time was 4.4 days by follow up examination. Subjective questionnaire response had a mean wearing time of between 6 and 7 days. The refractive error distribution peaked at -0.75 diopters (D) with a skewed distribution toward higher amounts of myopia. The military rank distribution of participants approximately split between commissioned and warrant officers; the enlisted ranks included a few crew chiefs and aerial observers. Lens type distributions matched the refractive error distribution, except for RGP lenses, which were equally distributed across refractive error. The distribution of subjects by age was bimodal, with peaks near ages 27 and 37. Because of the bimodal age pattern, there was some concern that our sample was not representative of Army aviation in general, so the Aviation Epidemiology Data Register was queried regarding the entire aviation population. All of the 1989 flight physical data were reviewed (as was 6 months worth of 1990 data); a similar bimodal distribution was obtained, thereby reassuring the investigators that the sample was not biased in some fashion.

To date, safety issues have not arisen, although two contact lens wearers happened to be involved a midair mishap. Both occupied the front seat of involved AH-64s, neither individual was at the controls at the time of the mishap, and U.S. Army Safety Center assessments did not include contact lens wear as a factor in the mishap. Additional areas of interest included clinical and basic physiological data: Anterior contact lens surface pH, lens hydration, tear film stability, corneal thickness, objective biomicroscopic examination, and endothelial morphology. These subjects will be addressed both individually and in a correlated format through the open literature prior to final government technical report.

Subjective questionnaire data were highly supportive of contact lens wear while performing flight duties. Approximately 90 percent of subjects felt their flight performance with contact lenses was equal to or better than with spectacles after 1 month of contact lens wear; after 3 months, all subjects felt their flight performance with contact lenses was equal to or better than with spectacles. Confidence in flight abilities with contact lenses paralleled the above findings, as did combat effectiveness estimates and endorsement of a routine program. Of some concern is the fact that 35 percent of the subjects admit on anonymous questionnaire to wearing their lenses longer than the 7 day maximum; 10 percent admit to going longer than 10 days continuous wear. This information could be valuable to attempts at modeling risk of adverse effects.

The true disposable contact lenses and wetting solutions have cost an average of $415/aviator/year; the annual cost of RGP lenses was essentially identical. However, the annual cost of the standard soft lens that was used as a disposable was $835/aviator. These costs are minimal compared to the expenses incurred via normal high performance aircraft training and operational activities. However, there are hidden costs to a proposed routine contact lens program that must be further documented: Optometric manpower requirements for required fittings and follow-up exams are still being evaluated, establishment of a logistical train for resupply is still under consideration, and finally the potential for adverse medical effects that are linked to routine contact lens wear can cost units in terms of operational availability of some aviators.

Ocular health incidents or adverse effects have been varied. Of the six medical events recorded, three cases are thought to be contact lens-related and three independent of contact lens wear. All cases involved subjects wearing soft lenses. One case of acute, localized ulcerative keratitis has been confirmed. The ulcer (and its secondary scar) was located superiorly off the visual axis, so visual acuity was unaffected. The individual was on Duty Not to Include Flight (DNIF) status for 10 days. Once the acute infection resolved, normal full flight duties (FFD) were resumed. The subject resumed contact lens wear 6 weeks after resuming flight duties. Two cases of generalized keratoconjunctivitis have been observed. Both were linked to a superficial corneal abrasion judged to be associated with improper soft lens removal techniques. Neither involved DNIF; recovery occurred within 3 days for both. The last three cases were thought to be unrelated to contact lens wear and included: One case of viral keratoconjunctivitis (FFD), one case of anterior uveitis (DNIF 6 days), and one acute allergic response (DNIF 2 days).

SUMMARY

Subjective approval of routine contact lens wear has been high, as have subjective performance assessments. Ocular risk for severe infection is difficult to establish from current data. However, cost in terms of lost flight duty time is being monitored. Medical costs, in terms of logistic and professional personnel requirements still have to be established. If current trends continue, it is possible a decision on the routine wear of contact lenses could be positive. However, because of unique difficulties encountered by presbyopes and high astigmats a significant portion of spectacle-wearing aviators will not be able to wear contact lenses. Consequently, routine contact lens wear represents only a partial solution to spectacle incompatibility problems. Therefore, developmental hardware alternatives must be included in future system programming or a large number of aviators will be prevented from performing certain flight duties.

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1. The views of the author do not purport to reflect the position of the Department of the Army or the Department of Defense.

2. Citation of trade names does not constitute official Department of the Army endorsement or approval of the use of such commercial items.

3. Human subjects participated in the study after giving their free and informed voluntary consent. The investigator adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

10 YEARS FLYING WITH SOFT CONTACT LENSES

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ABBREVIATIONS USED IN TEXT

ASCL Trial	=	Aircrew Soft Contact Lens Trial
V.A.	=	Visual Acuity
C.L.	=	Contact Lens
Q.R.A.	=	Quick Readiness Alert
C.F.S.	=	Corrected Flying Spectacles
A.R.5	=	Aircrew Respirator NBC No 5 Mk 2
I.A.M.	=	Institute of Aviation Medicine
Hz	=	Hertz
E/W	=	Extended Wear
H/W	=	High Water
LUN	=	Lunelle
S75	=	Scanlens 75
M.O.	=	Medical Officer
NAV	=	Navigator
MOD	=	Ministry of Defence
C.A.	=	Consultant Adviser

INTRODUCTION

In 1980 the RAF started an Aircrew Soft Contact Lenses (ASCL) Trial Phase 1, to assess the value and safety of Soft Contact Lenses for those Aircrew who normally wear Corrected Flying Spectacles.

For this trial two soft contact lenses were selected. The high water content Scanlens 75 and the medium water content Snoflex 50.

The reason for selecting such lense was that Front Line Aircrew may have to use their Optical Aid for long periods, eg QRA, DIVERSION, LONG HAUL FLIGHT.

METHOD

1. VOLUNTEERS were selected from Aircrew and Medical Officers.

Initially:

20 Volunteers were fitted with Snoflex 50 Lenses
20 Volunteers were fitted with Scanless 75 Lenses

2. All Volunteers were fit healthy males with no ocular pathology and no 'eye problems' apart from the need for spectacles to achieve best visual acuity. The matching of lens type and volunteer was randomized and did not relate to Aircrew role or age.

MEASUREMENTS

3. For the Initial Volunteers certain measurements were taken, pre-fitting and post fitting of the lenses. These consisted of:

Visual Acuity
Corneal Diameter
Inter-Palpheral distance in Primary Position
Corneal Thickness (Central Axis)
Schirmer's Test
Na/K Ratio in Tear Fluid
Osmolalaty of Tear Fluid

After the Environmental Tests at IAM, the only measurements which were continually monitored were Visual Acuity at each visit and the Schirmer's Test at the first visit for new volunteers.

4. All Volunteers when fitted with their soft contact lenses, started off on a daily wear regime so that they became accustomed to the handling and care of their lenses. This particular care system (cleaning lenses in the palm of the hand with Pliagel and rinsing thoroughly with Preserved Saline and then storing in Preserved Saline) and the regular visits initially imposed on the volunteers, deterred many from continuing in the trial. At Table 1 are listed those cases which fell by the wayside in the early years, and the reasons for abandoning their lenses.

The latter years, with less frequent visits to the Ophthalmologist and with early progress to extended wear use, have resulted in better compliance.

IAM ENVIRONMENTAL PHASE

Of the initial 40 Volunteers, 10 of each (Snoflex 50 and Scanlens 75) were to have the Environmental Tests carried out at IAM. Unfortunately due to Service needs and availability of IAM equipment, not all 20 subjects completed the Test programme. Despite this the results indicated that environmental flying conditions would NOT prejudice the use of Soft Contact Lenses in Aircrew.

IAM Report No 626
D H Brennan and J K Girvin
Aug 1983

ENVIRONS TESTED AT IAM

1.	HYPOXIA	12,000 feet and 27,000 feet	17 Subjects
2.	RAPID DECOMPRESSION	8,000 feet to 38,000 feet	8 Subjects
3.	PRESSURE BREATHING	30mm Hg and 70mm Hg for 30 and 45 Seconds	17 Subjects
4.	VIBRATION	Expected Decrement in V.A. at 6 and 8 Hz	17 Subjects
5.	ACCELERATION	4G and 6G	13 Subjects
6.	CLIMATIC TESTING	Hot 50°C 1 Hour Cold -25°C 1 Hour	13 Subjects
7.	AIRCREW RESPIRATION NBC No5	2 Hours	13 Subjects

CONCLUSION

The subjects were exposed to the most extreme adverse environmental conditions considered likely to be encountered by military aircrew in flight. In all instances, the visual performance of aircrew wearing soft contact lenses did not differ significantly from their performance when wearing CFS, and was not degraded by any of the environmental stresses. The visual performance of subjects wearing Scanlens 75 did not differ significantly from those wearing Snoflex 50. It was considered from the environmental standpoint soft contact lenses were suitable for aircrew.

Upon receipt of the environmental test results the volunteers were allowed to fly wearing their lenses.

In 1981 the Snoflex 50 lenses were abandoned because they were quite unsuitable for Extended Wear use due to discomfort and ciliary injection when used over 16 hours.

Scanlens 75 CLs have continued to be used and in a few cases Lunelle CLs have been used.

Some of the original volunteers have left the service and some have stopped wearing the lenses for the reasons given in Table 1.

In 1985 the care regime was changed to the SEPTICON care system BUT lenses were NOT to be cleaned (massaged) in the palm of the hand. CLERZ drops (no preservative and no enzyme) were used on waking when lenses were being used as E/W lenses.

QUESTIONNAIRE TO VOLUNTEERS IN THE RAF ASCL TRIAL

1. The above questionnaire included 3 specific questions related to the operational aspect of Soft Contact Lenses for Aircrew.

(a) Each Volunteer was asked did he prefer wearing Soft Contact Lenses to wearing spectacles.
All answered YES

(b) Each Volunteer was asked for his total flying hours in an operational role whilst wearing his Soft Contact Lenses. Flying hours in a Civilian or Service Passenger Aircraft were NOT to be included. The type of Service aircraft and the subject's operational role were to be included. ie. PILOT, NAVIGATOR, AEO, AEOp, Air Eng, ALM, AIR EXPERIENCE. THE TOTAL FLYING HOURS to date exceeds 30,000 hours. (Tables 2, 3, 4, 5, 6 and 7) give a breakdown of Flying Hours.

(c) Each Volunteer was asked if he had experienced any visual problems when flying wearing his Soft Contact Lenses.
All answered NO

(d) Each Volunteer was asked if he would be confident to fly operationally wearing Soft Contact Lenses.
All answered YES

At the present time there are 38 Volunteers in the ASCL Trial (June 1990). Of these, 8 are unilateral aphakes, ie they have had a cataract removed from one eye and had a Scanlens 75 Contact Lens fitted, and have retained a full flying category.

The breakdown of the current volunteers with their visual acuities and wearing time is given in Table 8.

All volunteers are regularly reviewed every 4 months.

CONCLUSION

1. It is the opinion of the author of this report that Soft Contact Lenses are a viable and well worthwhile alternative to CFS for Aircrew. Not all Aircrew will be suitable, but in most cases only a trial of lenses can decide this. Even while wearing Soft Contact Lenses the Aircrew member will always carry one pair of clear CFS with him.

The danger is that if you do not fit and supply such Optical aids for those who require CFS, the individual will go out and purchase his own contact lenses privately - and these persons will not be correctly supervised.

The Author has seen 3 such Aircrew. Two had Vascularigation of the Cornea and had to stop Contact Lens wear immediately. They were symptom free but had low water content daily wear soft lenses, supplied by an optician privately and they had not been reviewed regularly. The third had Allergic Conjunctivitis, also known as Giant Papillary Conjunctivitis. Again he was symptom free and had not been regularly reviewed by the Optician who had supplied his low water content daily wear lenses privately. He had to cease wear immediately.

RECOMMENDATIONS

1. If MOD decide to supply suitable Aircrew with Soft Contact Lenses, it is recommended that lessons learned in the ASCL Trial Phase 1 should be implemented in the "RAF ASCL Trial Phase 2".

(a) All Volunteers would sign a declaration form that they understood they were participating in a Trial and that they are aware of complications which can occur. A draft for such a form (Table 9) has been approved by the RAF medical ethical committee.

(b) In the opinion of the author the ideal Soft Contact Lens for Aircrew is a lens which

(i) Has an Extended Wear Capability.

(ii) Is a Disposable Lens.

(c) Such a lens would be fitted and issued as a Daily Wear Lens. The lenses would be removed each night and placed in a Cleaning System which contains no preservatives and no enzymes. Such a system is the 10/10 Cleaning System and this would replace the present Septicon system.

The subject would not have to clean the lens each night using the palm of his hand and fingers. The latter system was used early in the present trial and often caused damage to the lenses and the volunteers found it tedious. The present Septicon system avoids excess lens handling, but contains a preservative.

Minimal lens handling reduces lens damage and lens infection, and daily wear reduces the likelihood of Corneal Vascularigation developing.

(d) Having a disposable lens means that after 4 weeks wear, he discards his lenses and uses an identical new pair of lenses. Replacing lenses monthly reduces Protein deposits building up on the lenses with associated allergic reactions.

(e) Periodically the supervising ophthalmologist will have the volunteer use his lenses as extended wear for one week and will review him at the end of the week. This will enable the aircrew member to experience using the lenses in extended wear, as may be necessary in operational conditions, eg Diversion from main base, Harrier operation, Long haul flights.

It will be emphasised to the volunteers that the lenses are to be used as daily wear unless operational needs decree otherwise and only then.

Each Volunteer will carry a new pair of soft contact lenses with him at all times.

(f) Soft Contact Lenses should only be offered to experienced aircrew, ie 25 to 35 years of age. Fitting Trainee Aircrew who require CFS is NOT recommended. This has been discussed with the CA in Psychiatry who agrees that the stress of learning a flying role should not be influenced or impeded by concern or worry about contact lenses. In fact the contact lenses could become a ready scapegoat for failure in general airmanship.

It is felt that a qualified Aircrew person with experience is the ideal for a trial of contact lenses. Thus those in the 25 - 35 years age group, when they are at their highest profile in aircrew duties (particularly front line squadrons) should be the first recipients.

IMPLEMENTATION

1. OPHTHALMOLOGIST

Each Volunteer is to be supervised by a Service Ophthalmologist with Contact Lens experience.

2. OPHTHALMIC OPTICIAN

Fitting and supervision of Volunteers may be carried out by an Ophthalmic Optician working in a Service Ophthalmic Department who has direct access to the Ophthalmologist at Para 1.

3. SOFT CONTACT LENSES

SCANLENS 75 (H/W Content Soft Contact Lens)
LUNELLE (H/W Content Soft Contact Lens)
DISPOSABLE SOFT CONTACT LENSES TO BE CONSIDERED

4. CLEANING MATERIALS

10/10 Cleaning System. (No enzymes, no preservatives).

Clerz minims for use when lenses in situ and being used as Extended Wear. (Sterile and no enzymes and no preservatives).

5. AUTOMATED COMPUTER PACHOMETER

Prior to lens use and at yearly intervals thereafter.

6. ENDOTHELIAL PHOTOGRAPHY

Prior to lens use and at yearly intervals thereafter.

7. FITTING

Subjects will be fitted and issued with lenses at a suitably staffed and equipped Service Ophthalmic Department.

Subjects will be reviewed regularly - initially at least 4 monthly.

8. PROBLEMS

If any subject has any ophthalmic problems whilst wearing his contact lenses he is to remove his lenses, return to wearing his CFS, and be seen at one of the above centres within 24 hours.

REFERENCES

1. BRENNAN D H AND GIRVIN J K — 'The Suitability of Soft Contact Lenses for Aircrew' Aviation, Space and Environmental Medicine January 1985

2. J K CLOHERTY — 'Contact Lenses for Pilots and Aircrew in the Services' Paper 15. AGARD Conference Proceedings No 379 April 1985

TABLE 1

NOT SUITABLE. CEASED TO WEAR. SUBJECTS

SUMMARY

1. Four Volunteers were not suitable to be started on the Trial.

2. Those Volunteers started on the Trial and who ceased wearing their Contact Lenses can be divided into 2 Groups. Those (a) who ceased wear for their own reasons and who did not keep their Review appointments and those (b) who had their lenses stopped by the Medical Officer for clinical reasons.

a. (1) Three could not attend their Review appointments due to a busy Flying Programme.

(2) Twenty two ceased wearing their lenses because they found the cleaning regime tedious and lenses uncomfortable. These subjects wore their lenses ranging from 1 month to 2 years (mean 6 months), 12 wearing S50, 10 wearing S75. Some of these Volunteers reached the IAM Phase and then thought the Trial was over.

(3) Two subjects left the Service.

b. (1) One High Myope. Unsuitable. Lenses stopped by M.O.

(2) One Left Corneal Abscess.

(3) Two Cases Corneal Vascularization.

(4) One Allergic G.P.C.

(5) One Poor Stereopsis.

(6) One Poor Handling.

ie. Seven for clinical reasons had to cease wear.

TABLE 2

TYPE OF AIRCRAFT	HOURS	AIRCREW ROLE
SPITFIRE	100	PILOT (B of B)
HURRICANE	100	PILOT (B of B)
CHIPMUNK	100	PILOT
CHIPMUNK	25	PILOT
CHIPMUNK	1	PILOT
DEVON	100	PILOT
DOMINIE	100	PILOT
DOMINIE	30	MO - AIR EXP
DOMINIE	6	PILOT
DOMINIE	250	NAV
DOMINIE	100	NAV
DOMINIE	10	NAV
DOMINIE	30	NAV
BULLDOG	50	PILOT
VARSITY	100	NAV
JET PROVOST	100	PILOT
JET PROVOST	77	PILOT
JET PROVOST	200	NAV
JET PROVOST	20	NAV
JET PROVOST	30	NAV
JET PROVOST	50	MO - AIR EXP
CANBERRA	10	PILOT
CANBERRA	250	NAV
HUNTER	650	PILOT & MO
HUNTER	50	NAV
JET STREAM	150	PILOT
JET STREAM	15	PILOT
JET STREAM	25	MO - AIR EXP
JET STREAM	100	PILOT
	2730	

SPITFIRE HURRICANE CHIPMUNK DEVON DOMINIE BULLDOG JET PROVOST HUNTER CANBERRA JET STREAM	2730 HOURS	26 SUBJECTS

TABLE 3

TYPE OF AIRCRAFT	HOURS	AIRCREW ROLE
HELICOPTER - (9 Types)	500	PILOT (TEST PILOT)
HELICOPTER - Chinook, Wessex, Gazelle	20	MO - AIR EXPERIENCE
HELICOPTER - Wessex	2700	PILOT - S.A.R. ARMY SUPP.
HELICOPTER - Chinook, Sea King	30	PILOT - S.A.R. ARMY SUPP.
HELICOPTER - Gazelle	10	PILOT
HELICOPTER - Wessex, Sea King	125	PILOT - SUPP, TRIALS
HELICOPTER - Sea King	150	NAV - TORPEDO TRIALS
HELICOPTER - Gazelle	50	PILOT COMMUNICATION - NATO CMD
HELICOPTER - Gazelle	5	PILOT COMMUNICATION - NATO CMD
HELICOPTER - Gazelle, Lynx	80	PILOT - S.A.R. & SUPP.
HELICOPTER - Chinook	175	NAV - SUPP.
HELICOPTER - Puma, Wessex	3300	CREWMAN
HELICOPTER - Puma, Wessex, Sea King, Gazelle	50	MO - AIR EXPERIENCE
HELICOPTER - Gazelle	250	PILOT - VIP COMM.
HELICOPTER - Wessex	250	NAV
HELICOPTER - Wessex	800	A.L.M.
HELICOPTERS	---- 8495 HOURS	16 SUBJECTS

CHINOOK WESSEX SEA KING PUMA GAZELLE LYNX	8495 HOURS	16 SUBJECTS

TABLE 4

TYPE OF AIRCRAFT	HOURS	AIRCREW ROLE
V.C. 10	25	AIR EXP - MC
V.C. 10	2850	M/ENG
V.C. 10	10	PILOT
TRISTAR	1000	PILOT
TRISTAR	500	PILOT
HERCULES	100	PILOT
HERCULES	30	PILOT
HERCULES	10	AIR EXP - MO
HERCULES	600	MALM
NIMROD	150	NAV
	---- 5275	

V.C. 10 TRISTAR HERCULES NIMROD	5275 HOURS	10 SUBJECTS

TABLE 5

TYPE OF AIRCRAFT	HOURS	AIRCREW ROLE
HAWK	240	PILOT
HAWK	850	PILOT & MO
HAWK	30	PILOT
HAWK	200	PILOT
HAWK	15	PILOT
HAWK	3800	PILOT
HAWK	100	AIR EXP - MO
HAWK	250	NAV
BUCCANEER	150	NAV
BUCCANEER	10	NAV
LIGHTNING	100	NAV
LIGHTNING	100	PILOT
LIGHTNING	500	PILOT
PHANTOM	100	NAV
PHANTOM	200	PILOT
PHANTOM	500	PILOT
PHANTOM	190	PILOT
JAGUAR	500	PILOT
JAGUAR	50	AIR EXP - MO
JAGUAR	20	NAV
JAGUAR	200	NAV
	8105	
HAWK BUCCANEER LIGHTNING PHANTOM JAGUAR	8105	21 SUBJECTS

TABLE 6

TYPE OF AIRCRAFT	HOURS	AIRCREW ROLE
HARRIER	200	AIR EXP - MO
HARRIER	20	NAV
HARRIER	20	AIR EXP - MO
HARRIER	100	PILOT
TORNADO	1500	PILOT
TORNADO	800	NAV
TORNADO	500	NAV
TORNADO	200	NAV
TORNADO	5	NAV
	3345	

HARRIER TORNADO	3345 HOURS	9 SUBJECTS

TABLE 7

CENTRIFUGE

352 Runs in Centrifuge

96 6 - 7 G

41 7 G M.O.

Rest Less Than 6 G

1 Run on USAF SAM Centrifuge 9 G

DECOMPRESSION CHAMBER

1. 50 HOURS at 25,000 feet
2. EXPLOSIVE DECOMPRESSIONS M.O.

   8K → 25K - 100
   25K → 45K - 2

TABLE 8

SUBJECT REFERENCE

			R	L	
7	LUN	M.O.	6/9	6/9	W/T Daily Wear due Vasc.
9	S75	M.O.	6/6	6/5	W/T 1/52. Out 24 hrs.
10	S75	M.O.	6/6	6/6	W/T 1/52. Out 1 night.
11	S75	NAV	6/6	6/5	W/T Daily. Dry Eye Vasc.
12	S75	PILOT	6/12 To Avoid Use of Rdrs	6/9	W/T Daily. Dry Eyes. Vasc.
13	LUN	PILOT	6/6	6/6	W/T Daily. Dry Eyes. Vasc.
18	S75	M.O.	6/6	6/6	W/T 1/52. Out 1 night.
19	LUN	NAV	6/6	6/6	W/T 1/52. Out 1 night.
20	S75	NAV	6/6	6/6	W/T 2/52. Out 48 hrs. Lenses Stopped - Vasc.
21	S75	NAV	6/12 6/6 with correction	6/6	W/T 5 days. Out 48 hrs. Vasc.
23	S75	ALM	6/6	6/6	W/T 1/52. Out 24 hrs.
27	S75	PILOT	6/6	6/6	W/T 1/52. Out 1 night. Lenses stopped 1969. Vasc.
30	S75	NAV	6/6	6/6	W/T 1/52. Out 1 night.
33	S75	NAV	6/6	6/6	W/T 1/52. Out 1 night.
44	LUN	M.O.	6/6	6/6	W/T Daily. Vasc.
46	S75	ENG	6/12 To Avoid Use of Rdrs	6/12	W/T 1/52. Out 1 night.
47	S75	NAV	6/12 To Avoid Use of Rdrs	6/12	W/T Daily. Dry L eye.
51	S75	ENG	6/6	6/9	W/T 2/52. Out 48 hrs.
53	S75	NAV	6/9	6/6	W/T 1/52. Out 1 night. Changed to Daily Wear Nov 89. Vasc.
54	S75	PILOT	6/6	6/6	W/T 1/52. Out 1 night.
55	S75	M.O.	6/6	6/6	W/T 1/52. Out 1 night.
56	S75	ALM	6/6	6/6	W/T 2/52. Out 48 hrs.
57	S75	PILOT	6/6	6/6	W/T 6 days. Out 24 hrs.
58	S75	PILOT	6/9 N12	6/24 N5	W/T 1/52. Out 1 night. (R DIST L NEAR CORRECTION)
59	S75	PILOT	6/6	6/6	W/T 1/52. Out 1 night.
60	S75	PILOT	6/6	6/6	W/T 6 days. Out 24 hrs.
62	S75	PILOT	6/6	6/6	W/T 3 days. Out 1 night.
63	S75	PILOT	6/6 N9	6/18 N5	W/T 1/52. Out 24 hrs. (R DIST L NEAR CORRECTION)
64	S75	M.O.	6/6	6/6	W/T 3 days. Out 1 night.
66	S75	NAV	6/6	6/6	W/T Daily. Vasc.

TABLE 8 (Cont)

A1	S75	PILOT	6/6 WITH CLF & CFS	6/6 with CFS	W/T 1/52. Out 1 night. (R APHAKIA)
A2	S75	PILOT	6/24 with CFS	6/6 with CL & CFS	W/T 1/52. Out 1 night. (L APHAKIA. R CAT developing)
A3	S75	NAV	6/6 with CL	6/9 with CL	W/T 1/52. Out 1 night. (L APHAKIA. R MYOPIC)
A4	S75	PILOT	6/6 with CL & CFS	6/6 without	W/T 1/52. Out 1 night. (R APHAKIA)
A5	S75	ALM	6/6 with CL & CFS	6/9 without	W/T 1/52. Out 1 night. (R APHAKIA)
A6	S75	PILOT	6/6 with CFS	6/9 with CL	W/T 1/52. Out 24 hrs.
A7	G.P. Hard	PILOT	6/9 with CL	6/6 without	W/T Daily.
A8	S75	PILOT	6/6 with CL	6/6 without	W/T Daily wear. (R APHAKIA)

TABLE 9

VOLUNTEER IN AIRCREW SOFT CONTACT LENS (ASCL) TRIAL

Number ______________ Rank ___________ Name ____________________ DOB _____________

1. I understand that I am a volunteer in the above trial, which is designed to ascertain the long term safety of such lenses for those aircrew who are normally required to wear corrected FS when flying.

2. I understand that complications can occur when using extended wear soft contact lenses and also when they are used as daily wear lenses; for example, vascularization of the cornea or infections in the cornea. For this reason I understand that I must attend my regular ophthalmic review appointments.

3. I understand that I must carry one pair of clear corrected flying spectacles with me when I am flying.

4. I understand that I may have to cease wearing my contact lenses if so advised by the ophthalmologist.

5. I understand that I may have to stop wearing my contact lenses after a 10 year period even though I am symptom free.

6. I understand that if any complication occurs I cannot claim compensation from the Ministry of Defence.

Signed . ...

PRINT NAME AND RANK ....

Witness ....

PRINT NAME AND RANK ....

Date ....

The Witness must be an RAF Ophthalmic Surgeon

SOFT CONTACT LENS WEAR & AVIATION

by

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SUMMERY:

Soft contact lenses has been proposed as an alternetive to spectacles, when refractive errors is corrected in high performance fighter pilots.
In the pressented study the effect on visual acuity was examined, when soft contact lenses were used during altitude simulated flying within a low pressure chamber.
From the study it can be concluded, that neither visual acuity nor visual comfort are effected by the use of soft contact lenses.
Based on the experience from one pilot, soft contact lenses seems to be superior to spectacles when refractive errors has to be corrected in high performance fighter pilots.

INTRODUCTION:

Good visual acuity is essential for pilots and other aircrew members when performing there duties.

The most common cause for reduced visual acuity is refractive errors such as myopia and astigmatism.
To obtain normal visual acuity the refractive errors has to be corrected either by glasses, by contact lenses or by surgery.
All types of correction will cause some problems for the aviator.
Glasses will distort the image - put stress on the binocular functions and interfere with use of helmet and headset.
During high performance flying glasses tend to fog and they easily move out of focus.

As an alternative to glasses, contact lenses can be used.
Contact lenses do not possess the optical problems seen when glasses are used.
Instead the contact lenses may fold, move from the cornea or they may be lost.
Further more the contact lens may induce corneal hypoxia - leading to corneal oedema and change of refraction (1).

The present study was conducted with the purpose to invetigate the possibility for pilots to wear the new disposable type of contact lenses during high performance flying.
The main study was designed as a simulated high performance flying in a low pressure chamber; comparable to similar studies using other types of contact lenses (2,3).
As a supplementary study one fighter pilot was fitted with soft contact lenses and instructed to report his subjective observations during standard tactical flight missions.

MATERIAL:

7 males aged 20 to 37 years participated in the study.
None of the subjects had a history of previous eye diseases.
Uncorrected visual acuity was 6/4 to 6/6 in all eyes, and the refraction ranged between emmetropia and + 1.0 diopters.
None of the subjects were using spectacles or contact lenses.

The contact lens used in the study was the Acuvue disposable lens designed for extended wear.
The lens is made from Etaficon A.
The water content is 58%. The base curve of the lens is 8.8 - 8.9 with a diameter of 14.0 mm.
This standard lens should fit most corneas with central K's within the range of 7.3 to 8.3. (4).

All contact lenses used in the present study had a spherical power of minus 0.5 dioptre.

METHOD:

For all test subjects the test was performed twice, one time with and one time without simulated altitude in the low pressure chamber.
During the 2½ hours testperiode, the simulated altitude was initially 8.000 feet for 30 min. Later the altitude was increaced to 24.000 feet followed by ½ hour at 8.000 feet before the test was finish. (See figure 1).
Descent- and ascent rate were 5.000 to 8.000 ft./min.

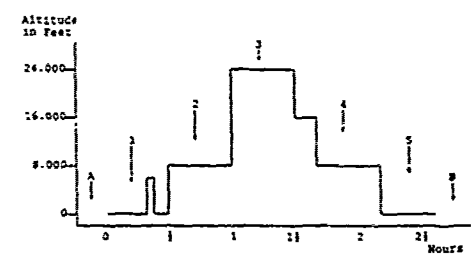

Figure 1: Pressure profile for simulated high performance flying in low pressure chamber.

Eyeexaminations indicated by A and B.
Visual acuity tests indicated by 1 to 5.

Visual acuity - refraction - corneal thickness and contrast sensitivity were measured before and after the test subjects were placed in the pressure chamber.
During the stay within the chamber, visual acuity was tested and subjective discomfort was reported every 30 min.
The position of the contact lens and lens fitting was followed by slit-lamp examination. Conjunctival or corneal injection, increaced tear production or signs of corneal oedema were reported as well.
Lenses were only placed in the left eye of the test subjects leaving the fellow eye as a control.

RESULTS:

During the test the test subjects were asked to describe any visual or ocular discomfort.
All subjects could feel the contact lens and 6 subjects complained of a minor sensation of dry eye in the eye fitted with a contact lens.
All subjects indicated the sensations as unimportent and without any implications on there perfoming capability.
One of the lenses had to be replaced by a new lens due to subjective discomfort caused by a 1 mm radial defect at the edge of the lens.

Visual acuity was measured using a Snellen and a near vision chard, before and after the test in the low pressure chamber.
During the stay within the chamber, visual acuity was followed by use of the VTA - tester.
No significant differences in visual acuity could be demonstrated between eyes with and eyes without contact lenses, neither at normal nor at low chamber pressure.
Minor fluctuations in visual acuity was observed in the majority of the eyes whether or not the eye was fitted with a contact lens. These changes in measured visual acuity were all within the range of 6/4 to 6/7.5, and between 20/15 and 20/25 on the VTA - system.

Refraction was measured subjectively and by autorefraction, before and after placing the contact lens in the left eye. After correcting the results for the power of the contact lens, the change in refractive power of the eyes could be followed.
In one eye the refractive variations measured by the autorefractor was 0.75 dioptre, in 8 eyes 0.5 dioptre and in 19 eyes 0.25 dioptre.
These changes are within the limits of confiders for autorefraction.
No difference was found between eyes with and eyes without a contact lens.

The corneal thickness was measured before and after the test in the low pressure chamber.
A minor tendency toward increasing corneal thickness on the eyes fitted with contact lenses compared to eyes without contact lenses was not significant.

The fitting of the leses was followed by slit-lamp examination, before, during and after the stay in the low pressure chamber. One lens folded and was displaced to the upper conjunctival fornix at the end of the test period. In all other cases the lenses stayed well centered at the cornea.

The development of conjunctival and ciliary injection, increased secretion or corneal oedema was followed during the test period by slit-lamp examination.

In 9 of the 14 tests a minor perilimbal injection was observed in eyes wearing a contact lens, compared to an identical observation in only 2 of the eyes without a contact lens.
Simulated altitude did not affect the limbal injection.

After removal of the contact lenses the eyes were stained with Fluorecein and Bengal rose.
In two subjects a minor Fluorecein staining was observed at the lower part of the cornea in both eyes as well after the first as after the second test.
Following staining with Bengal rose, a Bijsterveld score was calculated in all eyes.
Eight of the eyes fitted with a contact lens had a score of 2 or 3, compared to only 1 eye with a similar score out of the 14 eyes without a lens.
This difference is significant.
Bijsterveld score was independent of the altitude simulation.

One of our fighter pilots has been fitted with Acuvue contact lenses.
During the latest years the pilot had developed a myopia of 0.75 diopters in both eyes and had to use correcting glasses when performing his duties as a fighter pilot.
The contact lenses were only used during flying while the pilot othervise prefere not to use correction or to use spectacles.

The pilot has so far reported his experiences from more than 40 missions covering all aspects of tactical flying in a high performance aircraft.

On 2 occations one of the contact lenses were displaced to the upper conjunctival fornix. Both mission were compleated with only minor discomfort.
The reason for the displacement of the lenses may have been that the lenses were installed inside out. Both occations occured in the beginning of the test periode, in wich the pilot was less experienced in handling the lenses.

The pilot has concluded that the use of contact lenses is much more convenient than the use of spectacles during high performance flying.
By the pilots opinion standard glasses are nearly impossible to use during high performance flying, mainly because of the tendency to fog.

DISCUSSION:

From the study it can be concluded, that the use of soft Acuvue contact lenses does not reduce visual acuity nor do they induce refractive fluctuations when used during altitude simulated high performance flying.

Independent of the altitude simulation a slight perilimbal injection followed by staining with Bengal rose, and often a vague forein body sensation can be observed in 30 to 60% of the eyes, fitted with Acuvue contact lenses.

Based on our present experience we intend to recommend the use of soft contact lenses as an alternative to glasses, should myopia develope in a trained fighter pilot.
Due to the time consumption and possible problems when the lens is installed, it is recommended that the lens are worn constantly during periods on short time alert.
Even though contact lenses can be used during high performance flying, we still recommend that myopia disqualify an applicant, when fighter pilots are selected.

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ACKNOWLEDGMENT: The Acuvue contact lenses, used in the study has been donated by Synoptic a/s.

EFFECT OF AIRCRAFT CABIN ALTITUDE AND HUMIDITY ON OXYGEN TENSION UNDER SOFT AND HARD GAS-PERMEABLE CONTACT LENSES

by

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SUMMARY

The primary source of oxygen to the cornea is from the ambient air. Contact lenses decrease the oxygen getting to the corneal surface; and below a critical oxygen level corneal hypoxia occurs and the cornea swells. Repeated corneal edema may be implicated in the adverse effects of extended contact lens wear. The military flying environment includes aircraft cabin pressure that is decreased from normal sea level and cabin humidity that is usually much lower than normal. A calculational approach was used to assess the effect of various cabin environments on oxygen levels under both soft and hard gas-permeable (HGP) contact lenses. The oxygen tension under 55% and 71% H_2O soft lenses during normal wear and at 18% relative humidity and under HGP lenses of various oxygen transmissibility was calculated for 8,000 ft and 16,000 ft cabin altitudes. Both altitude and dehydration affect the oxygen under soft lenses, while hard lenses do not dehydrate and have the benefit of added oxygen with tear exchange during blinking. The calculated oxygen tension under the hard lens is 2-3 times that under soft lenses at all cabin altitudes. In normal soft lens extended wear the cornea deswells the following day; however, during flight, the lower oxygen under soft lenses could affect corneal recovery in aircrew. The cabin environment is shown to result in calculated oxygen levels under contact lenses that are substantially reduced from normal, and needs consideration.

INTRODUCTION

The primary source of oxygen to the cornea is from the ambient air. Contact lenses decrease the amount of oxygen getting to the corneal surface; and below a critical oxygen level, debated to be between 40-75 mmHg, corneal hypoxia occurs and the cornea swells (Mandell and Farrell, 1980; Holden et al., 1984). The adverse military flying environment includes aircraft cabin pressure that is decreased from normal sea level and cabin humidity that is usually much lower than normal. This cabin environment is shown to result in calculated oxygen levels under contact lenses that may be substantially reduced from normal, and needs consideration.

Military Aircraft Cabin Pressurization

At sea level, the ambient air pressure is about 760 mmHg (14.7 psi); however, the ambient pressure rapidly decreases as altitude increases (Gillies, 1965). U.S. Air Force aviation can be divided into two basic aircraft cabin pressurization schedules (Heimbach and Sheffield, 1985). Both are isobaric-differential pressurization systems in which cabin pressurization begins as the aircraft ascends through 5,000-8,000 ft and then the isobaric function maintains this pressure until a preset pressure differential (psid) is reached between the ambient and cabin pressure. This psid is then maintained with continued ascent, and the resulting cabin pressure can be written as: Ambient psi + psid = Cabin psi.

The typical cabin pressurization schedule for Fighter-Attack-Reconnaissance (FAR) aircraft is shown in Figure 1. For FAR aircraft the cabin may be unpressurized to about 8,000 ft altitude (10.9 psi), then cabin pressure is held at this altitude until a pressure differential of 5.0 psid is reached at 23,000 ft (5.9 psi). This 5.0 psid is then maintained as aircraft altitude increases. Thus, at an altitude of 30,000 ft (4.36 psi) the FAR cabin altitude is 12,000 ft (9.36 psi), and at 40,000 ft (2.72 psi) the FAR cabin altitude is about 17,000 ft (7.64 psi). For Tanker-Transport-Bomber (TTB) aircraft, the cabin can be held near sea level until the preset pressure differential, usually 8.6 psid, is reached at 23,000 ft (14.7 - 8.6 = 5.9 psi). At an altitude of 30,000 ft (4.36 psi) the TTB cabin altitude is about 3,500 ft (12.9 psi) and at 43,000 ft (2.36 psi) the TTB cabin altitude is about 8,000 ft. Military aircraft routinely fly in the 30,000 - 40,0000 ft altitude range, thus cabin altitudes will frequently be between 8,000 ft (565 mmHg pressure) to 16,000 ft (412 mmHg pressure).

FIGHTER COCKPIT PRESSURE SCHEDULE

(ISOBARIC-DIFFERENTIAL SYSTEM)

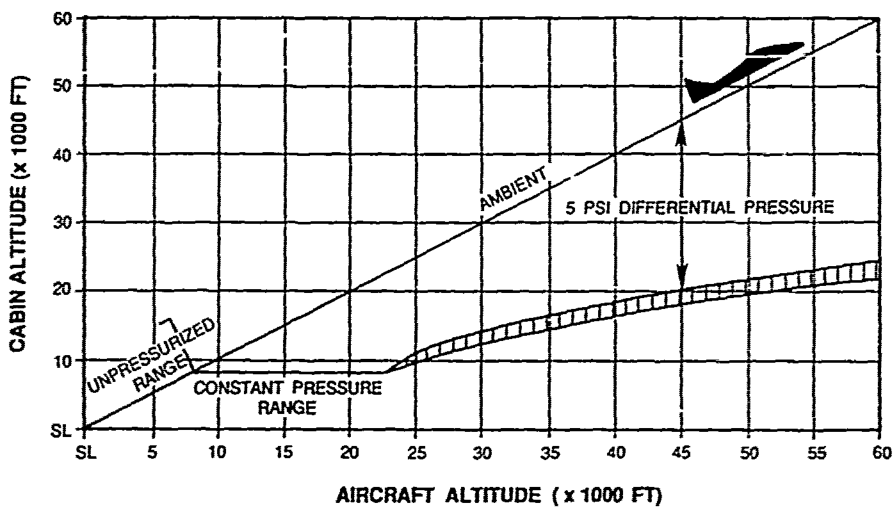

FIGURE 1.

OXYGEN TENSION AT THREE ALTITUDES

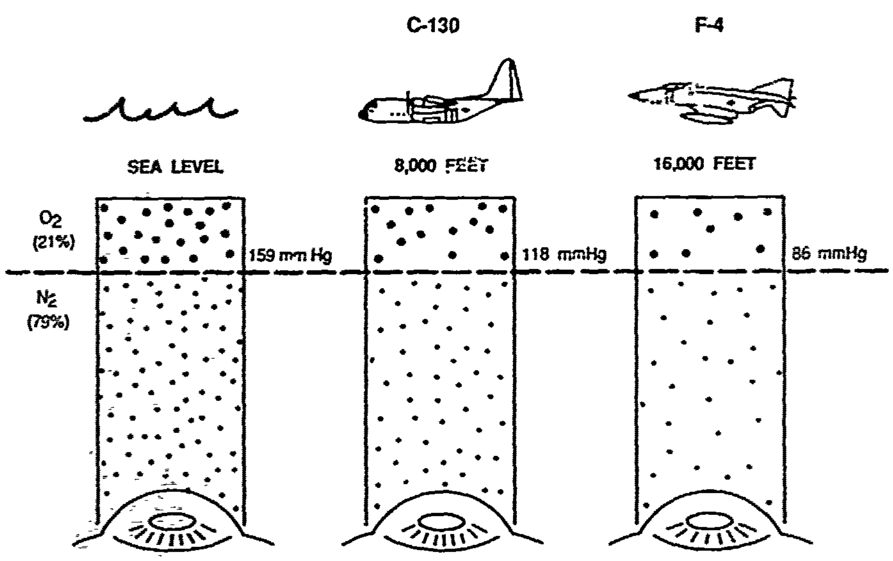

FIGURE 2.

Cabin Environment and Contact Lenses

Oxygen makes up about 21% of air at any altitude, and thus oxygen pressure is also reduced at higher altitudes. At sea level, the partial pressure of oxygen (PO_2) is 159 mmHg (760 mmHg x .21), but is 118 mmHg PO_2 (565 mmHg x .21) at the 8,000 ft cabin altitude and only 86 mmHg PO_2 (412 mmHg x .21) at the 16,000 ft cabin altitude (see Figure 2). The amount of oxygen passing through a contact lens is directly related to the PO_2, or "driving force" of oxygen, in the air (Fatt, 1978). At higher altitudes the oxygen under a contact lens must therefore be lower. In addition, lower humidity is known to result in partial dehydration of soft lenses (Andrasko and Schoessler, 1980). Since oxygen passes through the fluid phase of a soft lens (Fatt, 1978), any water loss will decrease the oxygen transmission of the lens. Also, virtually no tear exchange occurs with soft lenses (Polse, 1979), and the oxygen under these lenses is due to diffusion through the lens. Conversely, hard gas-permeable (HGP) lenses do not dehydrate and have the added benefit of the "pumping" of oxygenated tears under the lens during blinking (Fatt and Lin, 1976). This tear exchange increases the level of oxygen under HGP lenses by about 7-15 mmHg PO_2 above the amount from diffusion (Efron and Carney, 1983; Fatt and Liu, 1984).

A number of studies in altitude chambers and aircraft have assessed the subjective, visual, and corneal responses to contact lenses at aviation altitudes and low humidity levels (Eng et al., 1978, Eng et al., 1982; Brennan and Girvin, 1985; Flynn et al, 1986; Dennis et al, 1988). In general, they report only minimal corneal surface abnormality, variable subjective irritation, and little or no effect on visual acuity. However, there have apparently been no studies to assess the corneal swelling response in these environments. Although marked corneal edema would be necessary to affect the parameters measured, moderate corneal swelling may still be occurring. This may be important to the military aviator since repeated corneal edema has been implicated in the cause of a number of corneal complications, such as epithelial microcysts, during contact lens extended wear (Weissman and Mondino, 1983; Polse et al., 1987).

"Acceptable" Corneal Swelling/ Minimum Oxygen Level

Published findings allows an attempt to derive an "acceptable" oxygen level under a contact lens. Holden and Mertz (1984) suggested that a contact lens with an oxygen transmissibility (Dk/L) of about 35 x 10^{-9} worn during sleep causes an allowable amount of corneal swelling for most individuals to return to normal corneal thickness the following day. The results of Polse et al. (1987) support that this Dk/L level reduces corneal complications during extended wear. These studies found approximately 8% corneal swelling with this Dk/L; which is about twice the 4% swelling that occurs normally each night during sleep in individuals not wearing lenses (Mertz, 1980). Adopting such a 2x normal swelling criterion would seem prudent. Repeated high levels of overnight corneal swelling appear to adversely affect not only the corneal epithelium but also induce morphological changes in the corneal endothelium (Schoessler, 1983). These morphological changes may have an effect on endothelial ability to maintain normal corneal hydration (O'Neal and Polse, 1986), of which the long term effects on corneal health have not been determined. The minimum oxygen level under a lens occurs during the critical closed eye period of extended wear when the ambient oxygen pressure from the palpebral conjunctiva is decreased to only 55 mmHg PO_2 (Efron and Carney, 1979). A contact lens with a Dk/L of 35 x 10^{-9} has a calculated oxygen tension under the lens during eye closure of about 25 mmHg PO_2 - the proposed "acceptable" minimum oxygen level.

Approach

A calculational approach is used to assess the possibility of corneal hypoxia with contact lenses during military flying operations. The oxygen under both soft and HGP contact lenses is calculated for sea level, two cabin altitudes, and two levels of humidity. Given the assumptions involved in the calculations, the oxygen levels determined, although probably close, may not be the actual values. However, these calculated oxygen levels allow relative comparisons between lenses under military cabin environments and can also be compared to the proposed "acceptable" oxygen level. The calculations suggest corneal hypoxic conditions could occur, particularly with soft lenses, that may approach the hypoxia that occurs during overnight wear. The resulting corneal edema may be high in some cases; however, the actual amount of corneal edema needs to be measured. Regardless, the maximum corneal edema and frequency to be allowed, remain debatable.

OXYGEN TENSION UNDER LENS

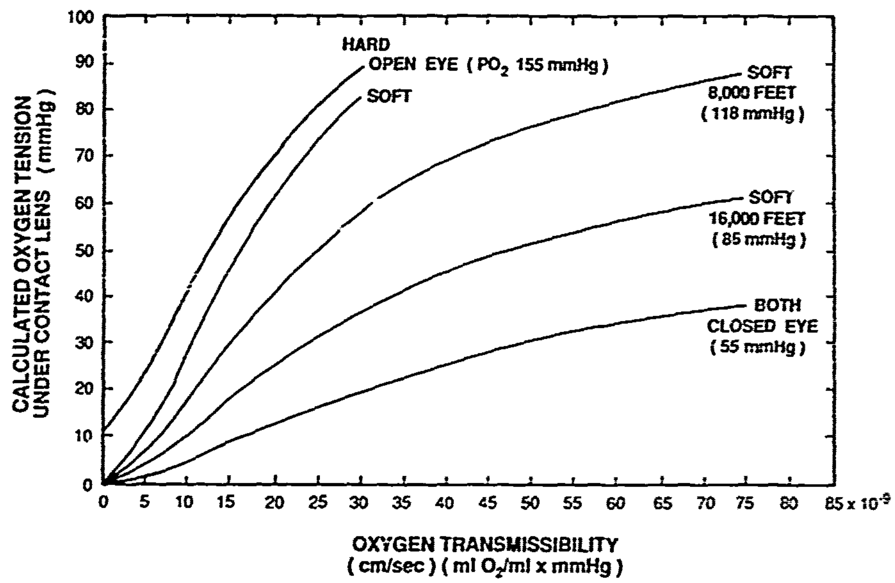

FIGURE 3.

TABLE 1.

EFFECT OF HUMIDITY ON SOFT LENS OXYGEN TRANSMISSION

HUMIDITY LEVEL	% H_2O	L ($\Delta L/L$)	CAL Dk*	CAL Dk/L‡
55% H_2O LENS				
VIAL	55%	.090 (1.00)	19.2	21.3
NORMAL	51%	.086 (.96)	16.2	18.9
18%	47%	.085 (.94)	13.8	16.3
71% H_2O LENS				
VIAL	71%	.210 (1.00)	37.0	17.6
NORMAL	66%	.200 (.95)	30.1	15.1
18%	58%	.183 (.87)	21.7	11.9

DATA IS FROM TABLE 4 OF FATT AND CHASTON (1982)

* x 10^{-11} (cm^2/sec)(ml O_2/ml x mmHg) $Dk = 2.00 \times 10^{-11} \exp(0.441 \times \% H_2O)$

‡ x 10^{-9} (cm/sec)(ml O_2/ml x mmHg)

CALCULATION OF OXYGEN TENSION UNDER CONTACT LENSES

General Equation

The equations and values of the empirical constants for calculating oxygen tension under a gas-permeable contact lens without the presence of tear pumping were given by Fatt and St. Helen (1971). The contact lens and cornea are considered to be tightly joined and the oxygen flux through the lens, j_d, is taken to equal the oxygen flux, j_c, into the cornea. From $j_d = Dk/L(P_a - P)$ and $j_c = \alpha P^{1/2}$, setting these equal and rearranging gives the useful equation: $Dk/L = \alpha P^{1/2}/(P_a - P)$, where Dk/L is the lens oxygen transmissibility, α the empirical constant 0.24 x 10^{-6} ml O_2/cm^2 x sec x (mmHg)$^{1/2}$, P_a the ambient oxygen tension at lens surface, and P the oxygen tension at the corneal surface.

The condition of little or no tear pumping applies to all soft contact lens wear (Polse, 1979) and for hard lenses worn during eye closure (O'Neal et al. 1984). Using this equation, the relationship between lens oxygen transmissibility and calculated oxygen tension under a contact lens is shown in Figure 3 for soft lens open eye wear at sea level and at 8,000 ft and 16,000 ft cabin altitudes. Also shown, for comparison, is the low oxygen tension under the lens calculated for the critical closed eye overnight period of extended wear. The upper curve in Figure 3 shows the higher level of oxygen under hard versus soft lenses during open eye wear.

Effect of Humidity on Soft Lens Oxygen Transmission

Since oxygen passes through the fluid phase of a soft lens, the diffusion (D) and solubility (k) of oxygen in the lens is related to the amount of water in the lens (Fatt, 1978). Fatt and Chaston (1982a) derived the relationship between the oxygen permeability (Dk) and percent water content ($\%H_2O$) of a soft lens at eye temperature as, Dk = 2.00 x 10^{-11} exp (0.0411 x $\%H_2O$). Lower humidity results in partial dehydration of soft lenses; and Fatt and Chaston (1982b), using the data of Andrasko and Schoessler (1980), have listed the effect of lower humidity on various soft lens parameters, including percent water content and lens thickness. Using data in their Table 4, the oxygen transmissibility (Dk/L) of the soft lens in the vial, during normal wear, and at a low 18% relative humidity was calculated and is listed in Table 1 for two water content (55% and 71% H_2O) soft lenses having .09 and .21 mm average lens thickness, respectively.

The ambient oxygen transmissibility (Dk/L) during normal wear is lower than vial Dk/L by 11.3% and 14.2% for the 55% and 71% H_2O lenses, respectively. This decrease in oxygen transmissibility becomes substantial under low (18%) humidity, with the ambient Dk/L now much lower than the vial Dk/L by 23.5% and 32.4% for these lenses, respectively.

Effect of Humidity/Altitude on Oxygen Tension Under Soft Lenses

The aircraft cabin environment includes both lower humidity and cabin pressure that is decreased from normal sea level. Aircraft cabin humidity is frequently between a very low 5% to 10% relative humidity. Although data on lens changes is not available for these very low levels of humidity, the low 18% humidity data noted above shows a dramatic effect on lens oxygen transmissibility (Dk/L). Using the calculated Dk/L in Table 1, the calculated oxygen tension under 55% and 71% H_2O soft lenses in the vial, during normal wear, and at 18% relative humidity is shown in Table 2 for sea level, and at 8,000 ft and 16,000 ft cabin altitudes.

At sea level, the calculated oxygen under the lens is higher for the 55% vs 71% H_2O lens by 11 mmHg PO_2 (23.4%) during normal wear, and is 17 mmHg PO_2 (51.5%) higher in low 18% humidity. More significant for aircrew, the calculated PO_2 is 52.4% and 66.7%, higher for the 55% vs 71% H_2O lens at low 18% humidity at the 8,000 ft and 16,000 ft cabin altitudes, respectively. As a comparison, for the 16,000 ft altitude and low humidity aircraft cabin the oxygen tension under the 71% H_2O lens approaches the very low oxygen level calculated for soft lenses during overnight closed eye wear.

Effect of Altitude on Oxygen Tension Under HGP Lenses

During open eye wear of hard gas-permeable (HGP) contact lenses, tear exchange with blinking increases the level of oxygen under the lens. Efron and Carney (1983), using the Equivalent Oxygen Percentage (EOP) polarographic sensor technique reported an average increase of about 2% O_2 (15 mmHg PO_2) under hard lenses with blinking. The time average oxygen tension under hard contact lenses has been computed by Fatt and Liu (1984). The upper curve in Figure 3, as adapted from their Figure 2, indicates approximately a 7-12 mmHg PO_2 (1-1.5% O_2) higher level of oxygen under hard versus soft lenses during open eye wear. Also, their equations show that the additional oxygen due to blinking is related to the ambient oxygen tension in the air.

TABLE 2.

EFFECT OF HUMIDITY/ALTITUDE ON OXYGEN TENSION UNDER SOFT LENS

HUMIDITY LEVEL	% H_2O	CAL Dk/L*	CALCULATED O_2 TENSION (mmHg) AT: SEA LEVEL	8,000 FT	16,000 FT
55% H_2O LENS					
VIAL	55%	21.2	62	42	25
NORMAL	51%	18.9	58	38	23
18%	47%	16.3	50	32	20
71% H_2O LENS					
VIAL	71%	17.6	58	38	23
NORMAL	66%	15.1	47	30	18
18%	58%	11.9	33	21	12

* $\times 10^{-9}$ (cm/sec)(ml O_2/ml $\times$ mmHg)

TABLE 3.

EFFECT OF ALTITUDE ON OXYGEN TENSION UNDER HGP LENS

LENS Dk/L*	CALCULATED OXYGEN TENSION (mmHg) AT: SEA LEVEL	8,000 FT	16,000 FT
20	70	49	31
25	80	59	37
30	89	67	43
35	97	74	48
40	105	80	52

PO_2 ADDED FOR TEAR EXCHANGE = 0.075 $\times$ AMBIENT PO_2

* $\times 10^{-9}$ (cm/sec)(ml O_2/ml $\times$ mmHg)

To derive the additional level of oxygen under hard lenses at the lower ambient oxygen tensions found in the aircraft cockpit, the ambient PO_2 was multiplied by 0.075 (7.5%). This factor seems appropriate, since it is equivalent to 1.5% O_2 (11.5 mmHg) at sea level (i.e. 1.5% of 760 mmHg), which is in the middle of the range between the calculated and EOP techniques noted above. The additional oxygen under hard lenses due to blinking was thus taken to be 9.0 mmHg PO_2 (118 mmHg x 0.075) at 8,000 ft and 6.5 mmHg PO_2 (86 mmHg x 0.075) at 16,000 ft cabin altitudes. The calculated oxygen tension under hard gas-permeable (HGP) lenses having oxygen transmissibilities from 20 x 10^{-9} to 40 x 10^{-9} (cm/sec)(ml O_2/ml x mmHg) is shown in Table 3 for sea level, and at 8,000 ft and 16,000 ft cabin altitudes.

The oxygen tension under a medium (30 x 10^{-9} Dk/L) oxygen transmissibility HGP lens is much higher than that for soft lenses (89 vs 58 mmHg PO_2) even at sea level alone. For the low 18% humidity condition, when the soft lens partially dehydrates and the hard lens does not, the calculated oxygen tension under the hard lens is 2-3 times that under soft lenses at all cabin altitudes. The oxygen tension under HGP lenses appears to be enough to prevent most corneal swelling, even for the low (20 x 10^{-9} Dk/L) oxygen transmissibility HGP lens at the 16,000 ft cabin altitude.

DISCUSSION

The calculated oxygen tension under 55% H_2O content soft lenses is higher than that for 71% H_2O lenses under all conditions, and is particularly noteworthy (up to twice the oxygen) for the low humidity, high altitude conditions found in the aircraft cockpit. For the low humidity environment, the medium water content lens was calculated to have the proposed minimum oxygen level of 25 mmHg PO_2 at the 8,000 ft altitude but not at the 16,000 ft cabin altitude; however, the high water content lens would not meet this minimum oxygen level at either altitude. Indeed, for the 16,000 ft cabin environment, the 71% H_2O lens is calculated to have the very low oxygen level that is found during closed eye overnight wear. These calculations suggest that high water content soft lenses may not be the best choice, at least from an oxygen standpoint, for wear in the military aircraft cabin environment. Lens dehydration in low humidity also affects soft lens parameters and fit, and may complicate the use of soft lenses by aircrew. It should be stressed that the oxygen levels presented are for a low 18% humidity, and the aircraft cabin frequently has a very low 5-10% humidity that would result in even lower oxygen levels and greater corneal hypoxia.

The calculated oxygen levels under soft lenses further suggest that normal everyday extended wear of soft contact lenses may not be a viable choice for military aircrew. The low oxygen level during overnight soft lens wear results in a substantial amount of corneal swelling in most individuals. In normal soft lens extended wear the cornea deswells the following day, although usually not completely (Holden and Mertz, 1984). However, during flight, the lower oxygen under the lens could cause corneal swelling and affect its recovery in both FAR and TTB aircrew. Thus, significant amounts of corneal swelling could be present not only at night, but during daytime flight as well, and would be even more compounded for those aircrew flying many hours in a day.

Corneal swelling may be related to a number of the corneal complications seen during extended wear, including epithelial microcysts and the non-reversible changes in endothelial morphology (i.e. polymegathism), and may predispose the cornea to some of the other complications seen in extended wear. The added burden of corneal edema during the daytime may result in a higher incidence of corneal complications during extended wear in military aircrew. Notwithstanding the oxygen question during flight, it is intuitive that the probability of complications increases as a function of years of extended wear. If the military adopts everyday extended wear for aircrew, then it can be expected that a number of aircrew will be lost due to complications from long term extended wear; many of which will be lost just when the pilots become fully trained and reach their peak. It would seem far wiser to maintain the corneal health with daily wear (nighttime removal) and switch to extended wear when necessary (i.e. flexible wear). This would allow the aircrew member to wear contact lenses over a greater number of years and help preserve this important resource.

Hard gas-permeable (HGP) contact lenses are calculated to have much greater levels of oxygen under the lens in the aircraft cabin environment than any soft lens. HGP lenses would generally have much more oxygen under the lens than the acceptable minimum oxygen level at both cabin altitudes. This higher oxygen level occurs because HGP lenses do not dehydrate in low humidity as soft lenses do; and get additional oxygen under the lens from the tear exchange that occurs with blinking, which does not occur with soft lenses. Importantly, HGP lenses can be made with much higher oxygen transmissibility and thus have much greater levels of oxygen under the lens at all times, particularly during overnight closed eye wear. Corneal deswelling the following day after overnight wear is much more rapid and much more complete, returning almost to normal, with HGP lens versus soft lens extended wear (see Figure 3 of O'Neal, 1988). This rapid corneal recover may be a critical factor in the much lower incidence of some corneal complications during extended wear (Polse et al., 1987).

The advantages of hard gas-permeable lenses for use by military aircrew would seem obvious from oxygen alone. Also, vision with hard lenses is generally better than with soft lenses, even more so for those with astigmatism. Results of a centrifuge study indicates that HGP lenses remain centered on the eye even under high G-forces and do not affect vision (Dennis et al., 1989). However, concern has been voiced about the possibility of foreign bodies under hard lenses and discomfort under dry conditions. Foreign bodies may not be the problem some imagine since anecdotal comments from a number of NASA astronauts indicate no problems during T-38 training flights and even during microgravity when there are many particles floating in the shuttle. Irritation with dry eye during low humidity may be a problem for some individuals, but this will also be the case when soft lens dehydration causes a tighter fitting and less comfortable lens.

The U.S. Navy has for years allowed non-pilots to wear contact lenses, and many of these rear-seat aircrew must by now be wearing hard gas-permeable lenses. If there had been significant problems with this lens type then comments would be known about; however, no such statements have been documented. Some individuals need soft lenses and some need HGP lenses to obtain the best vision and fit, and successful contact lens fitting will not occur without the use of both lens types. The USAF and European air forces should continue research into the use of HGP lenses in the FAR environment, as the potential advantages appear to be many.

In summary: (1) high water content soft lenses, at least from an oxygen standpoint, may not be the best choice for use in the cockpit environment, (2) long-term extended wear will most likely lead to a loss of aircrew due to increased corneal compromise over length of wear and is advised against, (3) flexible wear in which daily wear is used to preserve corneal health over many years of wear and extended wear when necessary is recommended, (4) hard gas-permeable lenses (HGP) have already been used successfully in fighter aircraft and would improve vision and corneal oxygen supply, and (5) flight studies of HGP lens wear in TTB and FAR aircraft are needed.

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INTRA-OCULAR LENSES AND MILITARY FLYING QUALIFICATIONS

by

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The development of IOL to the present day routine implantations was a path accompanied by euphoria, dramatic disappointments, rivalry, scathing criticism and hope (1, 2, 3). To understand this development in all its ramifications may I first present the definition for cataracts and a historical review of surgery methods.

The human lens which has become opaque and has thus lost its optical qualities is generally termed cataract.

A cataract can be defined according to its place of manifestation, i.e. subcapsular, cortical or nuclear cataract or according to its cause: e.g. congenital, metabolically or infect-induced, to name but a few.

The senile cataract may be found after the age of 60 with great variations, depending on way of life and place of residence.

Dr 1-induced cataract formation is for instance observed after an administration of st. oids.

The lens reacts very sensitively to ionizing radiation (beta, gamma, X-rays during therapeutical measures) as well as to excessive radiation exposure after UV- and infrared light.

A traumatically induced opacity of the lens may occur at any age.

Treatment with drugs even nowadays is the subject of controversal discussion - the best option is still the surgical cataract extraction.

At the beginning of this century the intracapsular cataract extraction was the method of choice his meant complete removal of the lens.

With the advancements of the instrumments, availibility of surgical microscopes, and implantation of ocular lenses extracapsular extraction became popular during the last decade. In this surgical technique the posterior crystalline capsule remains intact.

The first evidence in writing about lens implantation is provided by Casanova, an Italian adventurer, in whose memoirs aside from amorous affairs we find references to an Italian ophthalmologist by the name of Tardini, who is said to have implanted an artificial lens in 1765. Through Casanova the Dresden Court Surgeon Kassamatta learnt about this idea of lens implantation. There is evidence that he practised same in 1795, but it failed. The implanted glass lens submerged into the vitreous.

Then this method fell into oblivion for more than 150 years. Only in 1949 was the idea revived when a student of medicine asked Harald Ridley at the St. Thomas Hospital why he didn't replace the old opaque lens with an new one.

Ridley, an ophthalmologist in the Royal Air Force, jumped at the idea (3, 4). He benefitted from the extensive experience he had in the treatment of shell wounds in British war pilots. He had noticed that plexi glass splinters from the cockpit canopies which had frequently penetrated into the eye did not cause any foreign object inflammation. Moreover this material PMMA was easily brougt into shape.

As a site of implantation Ridley selected the spot of the original lens since this would most likely offer the best preconditions. On November 29, 194? he implanted the first postchamber lens following extracapsular cataract extraction - a pioneer's deed! News of this type of surgery was readily propagated and euphoriously accepted by the surgeons. For it seemed finally to be possible to replace the optically adverse cataract lenses and balance the problematical unilateral aphacia.

In the fifties Ridley implanted more than 750 IOL's. Binkhorst and Epstein in South Africa were recognized IOL-implanters. After short-term positive results problems were encountered. Here are a few:

To reduce these complications, avoidance of decentrations, the Frenchman Baron (5) in 1952 also started to implant lenses in the anterior chamber.

The hope, however, to reduce the rate of complications, did not materialize.

Endothel-decompensation, bullous Keratopathies (6, 7), uveitis, hypnema, glaucoma (8) and cystoid macular edema (9) were problems which made IOL-implantation appear as too risky! In part more than 70 % of the IOL's had to be explanted following complications which could not be controlled. A discouraging result!

Many turned their back on IOL-implantations, for some it was even detrimental to their reputation to continue implanting lenses. But there were pioneers who were fascinated by this idea and who considered it a challenge to master these complications.

The Dutchman Binkhorst anchored his lenses to the iris.

Starting in 1975 the IOL were again implanted at the site surely most favorable from an anatomical point of view. Once more it was C. Binkhorst (10) who took up cataract extraction preferred by Ridley and who recognized the advantages as far as complications are concerned.

Lens design and material were considerably improved, the surfaces polished, sterilization and instruments optimized. But how must the qualification for military flying duty with IOL be assessed?

Based on positive surgical success this question has found early positive answers in the German Luftwaffe. The German Air Force Institute of Aerospace Medicine meanwhile has 6 pilots respectively aircrew which continue respectively continued flight duty with an intra-ocular lens after surgery.
In 1986 and 1987 publications reported on intra-ocular lenses in 8 US Army pilots and 6 pilots of the US Air Force including discussions on advantages and disadvantages in comparison with contact lenses.

We like to present our experiences with IOL wearers.

In 1957 already a WW II pilot had been provided with an anterior chamber lens by Prof. Schreck, Erlangen. After a shell injury in 1941 and a cataract surgery in 1942 he was fitted a contact lens and flew as instructor pilot until the end of the war. During this period he had accumulated 5010 flight hours.

After 3 months he was reinstated into flight duty with a waiver. The eye operated on had a visual acuity of 1.0 with slight corrections.

For 13 years he flew another 3211 hours without any problems on all propeller aircraft of the Bundeswehr. In 1969 he suffered an ablatio retinae after contusion of the aphakic eye with visual loss on hand motions. After a Cerclage-surgery with lying anterior chamber lens he had regained a visual acuity of 1.0 after 4 months and flew another 500 flight hours until his discharge upon reaching his age limit.

These experiences were no grounds to hesitate issuing waivers for aphakic flight personnel if the visual requirements were met, even though the author at the ophthalmological clinic of the University of Munich has met a man after an accident who stood in front of him as admitting physician with the VK-lens in his hand which had been propelled from his operated eye.

In the meantime, however, lens material and especially the surgical techniques have improved to a degree as to preclude such cases nowadays.

The second pilot, a fighter pilot on an F-4F, was fitted with an Iris clip lens after a traumatic cataract and flew with a visual acuity of 1.25 seven months after the surgery on a jet until his discharge, totalling 1046 flight hours. Even an ejection after a mid-air collision incurred through no fault of his did not result in any dislocation of the lens.

The remaining 4 lens wearers of the flight personnel were fitted with posterior chamber lenses after ECCE. They all have full vision of at least 1.0. The average age of IOL-wearing subjects at time of surgery was 42 years. Whereas the genetically induced cataracts were operated on at an average age of 48, the traumatically-incurred ones were 10 years younger.

Disqualification for military flying duty after surgery lasted between 2 and 5 months. The average flight time before surgery was 3256 hours, afterwards between 33 and 3211, a mean of 257 hours.

Causes for cataracts:
3/6 Flying personnel traumat. cataract
2/6 flying personnel genet. cataract, 1/6 bilateral
1/6 cataracta complicata

Cataract Surgery Techniques

5/6 flying personnel ECCE-surgery
1/6 flying personnel ICCE-surgery

The following complications were found:

- one ablatio retinae after contusion with narrowing of visual field and vitreous opacities
- displacement of pupils through synechiae between crystalline capsule and intra-ocular lens

- temporarily more pronounced astigmatism
- one postoperative pressure increase, passing
- corneal scars
- slight decentration of IOL
- development of capsule membrane
- iris-sphinkter defects, pupillary margin defect.

In assessing whether flight crew should be granted waivers after cataract surgery with intra-ocular lens the surgery as such cannot meet the requirement. Every case must be evaluated separately.

The following criteria must be met:

1. The visual acuity must be 1.0
2. There must not be any measurable disturbances through glare
3. The intra-ocular eye pressure must be normal
4. There must not be any inflammatory processes

TABLE

Summary of individual aviator data

Subject	1	2	3	4	5	6
Flying status	Prop P.	Fighter P.	Fighter P.	Helicopter P.	Fighter P.	A/C Techn. Jet/Trop
Age at surgery	42 yrs.	36 yrs.	37 yrs.	46 and 47 yrs.	39 yrs.	50 yrs.
Year of surgery	1957	1979	1982	1986 and 1987	1989	1989
Cause of cataract	trauma	trauma	trauma	genetic	cat.complic.	genetic
Type of surgery	ICCE	ECCE	ECCE	ECCE	ECCE	ECCE
Type of IOL	VCL	ICL	HCL	HCL	HCL	HCL
Style of IOL	Schreck	---	Kratz	16 Morcher	Pharmacia Model 720	Intermedicin UV 51
Visual acuity before surgery	?	0.4 pp	0.05	0.4 and 0.4	0.4 p	0.32
Visual acuity after surgery	1.0	1.25	1.0	1.25 and 1.0	1.0	1.0
Corrective measures	+ 1.0/100°	+ 0.5-2.5/ 150°	- 0.5/100°	+ 1.75 + 1.75	---	- 0.25-2.75/165°
Return to flight status	2 months	7 months	8 months	6 + 3 months	17 months	2 months
Flight time before surgery	5010 hrs.	3020 hrs.	2465 hrs.	2350 hrs.	1835 hrs.	4855 hrs.
Flight time after surgery	3211 hrs.	1046 hrs.	638 hrs.	500 hrs.	115 hrs.	33 hrs.

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Cataract Surgery and Intraocular Lenses in USAF Aviators

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Abstract

More than one million cataract surgeries, most with implantation of intraocular lenses, are performed in the United States each year. We report the early data on the United States Air Force's prospective study on the use of these surgical techniques in its military flyers. From 1979 to 1990, 23 military aviators were evaluated by the United States Air Force School of Aerospace Medicine (USAFSAM) after cataract extraction with intraocular lens implantation. Their USAFSAM evaluation records were reviewed. Long-term follow-up (>3 years) was available on only 3 subjects. All 23 subjects were male Caucasians, with a mean age of 43 years. Ninety-one percent of the subjects were pilots, and, of these, 8 were qualified in high-performance aircraft. There were a total of 28 eyes, 86% (24) of which had received extracapsular cataract extractions (ECCE) with posterior chamber lenses. Best-corrected, postoperative vision was 20/20 or better in 100% of the eyes. Posterior capsule opacification occurred in 60% of the ECCE eyes, with one-third of those requiring Nd:YAG laser capsulotomies. Only one aviator was disqualified from flying duties for ocular reasons, a visually-qualified-to-fly rate of 96%. Eight aviators have actually flown since surgery. Although follow-up was short, the initial results are very encouraging.

Introduction

More than one million cataract surgeries are performed each year in the United States (U.S.) on individuals whose vision is sufficiently reduced to interfere with job performance or daily activities. More than 90% of these surgeries involve the implantation of an intraocular lens (IOL).[1] Cataract extractions, although common, are not without surgical and visual complications.[1-5]

Cataracts and cataract surgeries pose a particular problem for military aviators who may fly high-performance fighter, attack, or reconnaissance aircraft, often operate under night, low-level, or hostile weather conditions, frequently fly into unfamiliar terrain and airports, and may have to do all of this with special sensors such as night vision goggles. They are also routinely exposed to other environmental stressors, such as decreased partial pressure of oxygen, decreased humidity, and increased sunlight. They are required to have 20/20 or better, best-corrected vision in each eye in order to continue on flying status.

Before 1959, all aviators having cataract surgery were permanently removed from flying duties. From 1959 to 1984, 35 Air Force (AF) aviators had cataract surgery without an intraocular lens. Their vision was corrected by a hard or soft contact lens, and they were evaluated at the United States Air Force School of Aerospace Medicine (USAFSAM). Most of the aviators had received intracapsular cataract extractions. Of the 35 aviators, 25 received waivers allowing them to remain qualified to fly. Fifteen (60%) of these 35 aviators were pilots, of whom 2 were bilaterally aphakic. Only 2 of the ten aviators initially grounded were disqualified for ocular reasons, i.e., poor acuity.

The first aviator with an intraocular lens was evaluated at USAFSAM in 1979. A study group was formed, for the USAF Surgeon General, to prospectively study the aeromedical implications of this surgical technique. Since 1979, USAFSAM has evaluated 23 aviators who have had clinically-indicated cataract surgery with an intraocular lens. This initial report summarizes our findings and current aeromedical recommendations.

The Ophthalmology Branch at USAFSAM is particularly concerned about the impact of cataract surgery and intraocular lens implantation in this group of generally young adult males. In addition, the financial impact to the American public when a pilot is removed from flying duties is enormous. It currently costs up to $8 million and takes 4 to 5 years to train a fully combat-ready pilot.

Methods and Materials

Patient Selection

The Ophthalmology Branch at USAFSAM serves a consultant function to the USAF Surgeon General's Aeromedical Consultation Service for aviators who have been grounded for a disqualifying ocular condition or disease. United States Air Force aviators (flyers) are those personnel required to maintain stringent flying class II or III visual standards (i.e., pilots, navigators, and other aircrew members). Their visual acuity and various visual functions are checked annually by local flight surgeons. Patients are generally referred from their local flight surgeon to USAFSAM following diagnosis, treatment, and resolution or stabilization of any significant ocular problems. Once diagnosed as having had a cataract extraction with an intraocular lens, aviators were evaluated annually or every 2 years at USAFSAM. The records of all 23 aviators with intraocular lenses, who were seen at USAFSAM between 1979 and 1990, were reviewed. Additional data was obtained from the USAF Military Personnel Center (flying hours) and the USAF Safety Center (accidents/incidents).

Patient Evaluation

At each evaluation, a detailed history was obtained, focusing on the following points: age; sex; race; ocular trauma; family history; diagnoses; complications; eye(s) involved; dates of surgery(ies); type(s) of procedure(s) and lens(es); ocular symptoms before and after surgery; aeromedical disposition(s).

All aviators received a full, dilated ophthalmologic examination and special testing for each eye (O.U.) that focused on, but was not limited to, the following: visual acuities; refraction; pupillary reactions; external examination; stereopsis using the Vision Test Apparatus VTA-DP (25 arc seconds passes), the Verhoeff device (33 arc seconds passes), or the Howard-Dolman device (13 arc seconds passes); color vision using Pseudoisochromatic Plates (10 or more correct of 14 passes) or the FALANT Apparatus (all 8 correct passes); accommodation; intraocular pressure measurement; slit lamp examination; dilated retinal examination; keratometry. Recently, the aviators have also been tested for contrast sensitivity, glare effects, and mesopic vision (Rodenstock Nyktometer).

Diagnostic Criteria

Only aviators who had undergone cataract extraction with implantation of an intra-ocular lens were entered into this study group.

Results

Patients

All 23 aviators were male Caucasians on active duty in the USAF, AF Reserve, Air National Guard, or U.S. Army. Their ages, at initial evaluation, ranged from 25 to 53 years, with a mean of 43 years. This data is demonstrated in Figure 1. Twenty-one subjects (91%) were pilots, one was a flight surgeon, and one was a pararescue technician.

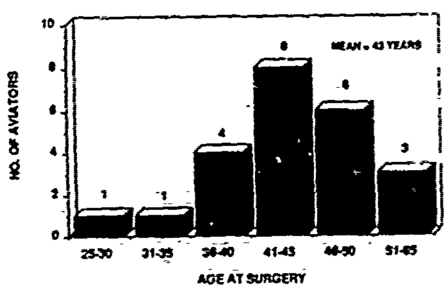

Figure 1. Distribution of aviators, by age, at the time of cataract/IOL surgery. Mean age was 43 years.

The average number of flying hours, at the time of surgery, was 4,632 for the pilots, 16 for the flight surgeon, and 800 for the pararescue jumper. Of the 21 pilots, 8 (38%) were qualified to fly fighter, attack, or reconnaissance (FAR) aircraft, and 13 (62%) were qualified in tanker, transport, bomber (TTB) or rotary-winged aircraft.

Follow-up Evaluation

The 23 flyers were evaluated on an annual or biennial basis, for as long as they remained in the Air Force. The longest follow-up was 6 1/2 years, but 44% of the aviators have had only one USAFSAM evaluation (Fig. 2). The mean follow-up was 18 months, with a range of from zero to 77 months. The USAFSAM has evaluated between 1 and 5 new IOL cases per year since 1983 (Fig. 3).

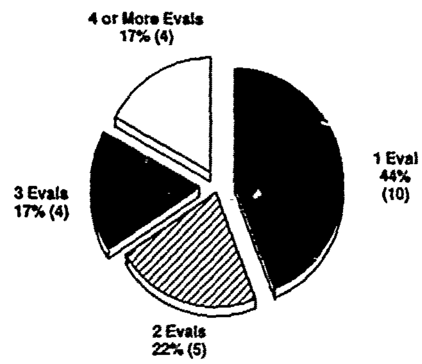

Figure 2. USAFSAM Cataract/IOL Study Group follow-up was 6 1/2 years.

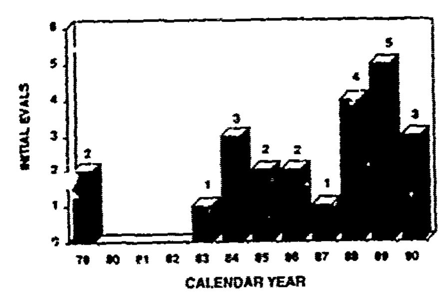

Figure 3. Initial USAFSAM evaluations, per year, of flyers status-post cataract/IOL surgery.

Etiology

Six aviators (26%) gave a history of prior blunt trauma to the involved eye. One additional aviator had Fuch's heterochromic iridocyclitis in the involved eye. Another flyer had prior pterygium surgery and postoperative beta-radiation to the involved eye, plus a family history of both parents having cataracts. One flyer gave a family history of cataracts in a first degree relative. Two flyers had a history of both blunt trauma and a family member with cataracts. Thus, 48% (11/23) had a possible specific etiology for the development of cataracts.

Number and Types of Surgeries

The left eye, alone, was involved in 12 (52%) of the flyers, the right eye in 6 (26%), and both eyes in 5 (22%) (Fig. 4). Thus, a total of 28 eyes underwent cataract/IOL surgery.

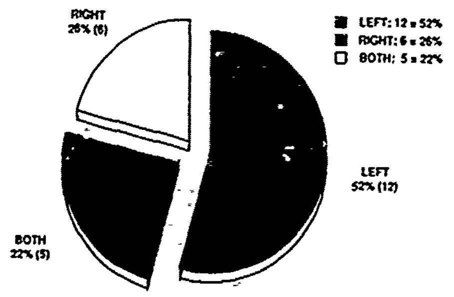

Figure 4. Eye(s) undergoing cataract/IOL surgery. The total number of aviators was 23.

The types of cataract surgeries performed is shown in Table 1. All of the eyes, with the exception of 3, had extracapsular cataract extractions (ECCE). Only one of the ECCE eyes had an anterior chamber implant (AC-IOL); the other 24 ECCE eyes had posterior chamber IOLs (PC-IOL). Thus, 86% of the eyes had ECCE/PC-IOL surgery. All of the IOLs were made of polymethyl methacrylate (PMMA).

Table 1. Types of cataract/IOL surgeries performed on USAF flyers (28 eyes).

	AC IOL	PC IOL	
ICCE	3	0	3 (11%)
ECCE	1	24	25 (89%)
	4 (14%)	24 (86%)	

Visual Performance

Visual performance, based on the last USAFSAM evaluation for each aviator, was outstanding. All of the eyes attained at least 20/20 best-corrected visual acuity for distance, and 23 eyes (82%) attained 20/15 best visual acuity. Twenty-two (96%) of the flyers passed a stereopsis test, 20 by Vision Test Apparatus-Depth Perception (VTA-DP) and 2 by the Verhoeff device. One subject failed all 3 of the stereopsis tests and was diagnosed as having a longstanding microtropia. All eyes passed the Pseudoisochromatic Plates color vision test.

Refractive Error

The residual, postoperative refractive errors, for the 28 eyes, were within the usual values seen. The mean, absolute spherical error was 0.83 diopters, with a range of from zero to 2.00 diopters. Eighteen eyes were myopic, 9 hyperopic, and 1 emmetropic.

The mean, absolute astigmatic error was 1.06 diopters, with a range of from zero to 3.75 diopters.

The mean bifocal add was +2.05 diopters, with a range of from +1.25 to +2.75 diopters.

Complications

Surgical and postoperative complications were relatively common. Most complications were minor, and all, except one, of the flyers had excellent outcomes.[5] The type and frequency of these complications are summarized in Table 2. Some eyes had more than one complication.

Table 2. Complications experienced by USAF aviators who underwent cataract/IOL surgery. The last four complications all occurred in one flyer.

Complication	No. Eyes	Percent	Non-USAF Rate	Reference
Opacified Posterior Capsule	15	60 of ECCE	Common	3
YAG-laser Capsulotomy	5	20 of ECCE	9.2-29%	3, 6, 7
Decentered IOL (No Acuity Impairment)	7	25	Unknown	
Prolonged Inflammation (Resolved)	3	11	Common	3
Ruptured Posterior Capsule	2	7	7.9%	8
Transient Elevated Intraocular Pressure	2	7	5%	4
Slipped Lens Requiring Second Surgery	1	4	Rare	4
Retinal Hole (Successfully Treated)	1	4	Unknown	
Persistent Uveitis (>4 weeks)	1	4	0.3-1.4%	3
Chronic Glaucoma	1	4	1%	9
Iris Hemorrhage Requiring Posterior Vitrectomy	1	4	Rare	8
Epiretinal Membrane	1	4	Unknown	

Intraoperative complications occurred in 3 eyes, consisting of ruptured posterior capsules in 2 eyes and an iris hemorrhage in 1 eye. The first 2 eyes underwent immediate anterior vitrectomies. The last eye required a posterior vitrectomy. Only 1 of these 3 eyes required an anterior chamber IOL.

Postoperatively, the most common complications were the following: opacified posterior capsules in 15 of the ECCE eyes (60%), of which 5 required Nd:YAG capsulotomies; mild to moderately decentered intraocular lenses in 7 eyes (no effect on visual acuity); mildly prolonged uveitis (> 4 weeks) in 3 eyes; elevated intraocular pressure in 2 eyes; epiretinal membrane in 1 eye.

Two eyes required second surgeries. One aviator had a slipped AC-IOL that required repositioning. One flyer, mentioned earlier under intraoperative complications, suffered an iris hemorrhage that required a posterior vitrectomy; he had persistent elevated intraocular pressure (glaucoma) and persistent uveitis, both requiring medications. He is the only flyer whose uveitis and/or elevated pressure required lengthy treatment.

A round retinal hole, with surrounding sub-retinal fluid, was discovered postoperatively in one of the aviators. This complication was treated with laser photocoagulation.

Thus, 5 aviators (5 eyes) had absolutely no complications.

Aeromedical Disposition

Of the 23 aviators, 19 (83%) were initially given waivers by the USAF Surgeon General for flying duties. Two aviators, who were visually qualified, were disqualified for cardiovascular disease.

Only 2 flyers were initially disqualified from flying due to ophthalmic disease. The flyer with the retinal hole described earlier, was "grounded" for 1 year and, then, returned to flying status. The other flyer was the individual who suffered the iris hemorrhage and required a posterior vitrectomy. He had persistent elevated intraocular pressure (average 39 pretreatment), chronic uveitis, a non-dilating pupil, an epiretinal membrane, and an internal wound gape.

Thus, the overall visual waiver rate was 96% (22/23).

Many of the older aviators were not actively flying. Eight flyers have been documented as returning to the cockpit. The types of aircraft they have flown and the flying hours they have accumulated, since surgery, are listed in Table 3. One flyer flew a FAR-type aircraft.

Table 3. Flying hours performed since cataract/IOL surgery by USAF aviators (N=8).

	HOURS	TYPE AIRCRAFT
FLYER 1	500	SMALL PROPS
FLYER 2	100	C-130
FLYER 3	300	F-16
FLYER 4	100	HELICOPTER
FLYER 5	200	C-130
FLYER 6	200	EC-135
FLYER 7	500	C-5A
FLYER 8	2100	C-5A

Discussion

Our study is the first to report on the use of intraocular lenses in USAF aviators who have undergone cataract surgery. Twenty-two of the 23 aviators, of whom 91% were pilots, were waived for flying status after careful aeromedical ophthalmologic evaluation at USAFSAM. The granting of waivers for intraocular lenses represents a major change in USAF policy, a great personal benefit for the individual flyer, and a savings for the taxpayers. However, even though the preoperative experience level was high (4632 average flying hours), only 8 aviators actually flew after surgery.

These USAF aviators are a relatively young subset of the general population undergoing cataract surgery. They also had been selected for normal eyes with excellent vision and no systemic diseases. It is, therefore, not surprising that their postoperative, best-corrected visual acuities were uniformly excellent (100%, 20/20 or better).

The types of surgeries and the intraocular lenses used paralleled technologic developments in ophthalmologic surgery. Extracapsular cataract extraction with posterior chamber IOL implantation was performed in 86% of our flyers, and this rate is comparable to that seen in the general population. Furthermore, the residual refractive errors are within the range usually found after this type of surgery.[10]

It was interesting that the left eye was the one most commonly involved. The reason for this, as well for the high incidence of prior trauma, is unclear.

All of the flyers received PMMA lenses. The literature supports the use of PMMA rather than silicone foldable implants, because of the higher rate of complications seen with silicone lenses. The latter lenses have a higher posterior capsule opacification rate (65.9% versus 28.6% for PMMA), complicate Yttrium-Aluminum-Garnet (YAG) laser capsulotomies, and have higher incidences of lens subluxation, corneal edema, and elevated intraocular pressure.[6, 11]

Multifocal IOL's cannot be recommended because of the small loss in best-corrected visual acuity and the large losses in contrast sensitivity and brightness. Additionally, it is still unclear what effect pupil size, lens tilt, and decentration will have on multifocal IOL performance. These lenses will not eliminate the need for spectacles to obtain best visual acuity; only the bifocal segment can be eliminated.[12]

Complications, although common, were generally minor and transient. The rate of posterior capsule opacification and YAG laser capsulotomy was moderately higher than is seen in the non-aviator population. This rate may be related to the flyers' younger ages.[3, 13] Also, an aviator with capsule opacification may be more likely to receive a capsulotomy to obtain 20/20 vision. None of our flyers developed a retinal detachment post capsulotomy. One pilot did complain of visual symptoms due to a capsulotomy that was too small. He noticed a blurred halo of light around lights, when his pupils dilated in the dark. Because this effect was monocular, he reported that he was able to ignore this distraction.

Minimally decentered IOL's occurred with moderate frequency (25%) but caused no reported edge-glare problems. Only 1 pilot complained of glare problems, and his IOL was well-centered. Koch and colleagues,[14] using the Miller-Nadler Glare Tester and the Baylor Visual Function Tester, found that posterior capsule opacification, decentration of the IOL, and increased pupillary size (more often present in younger individuals) are the principal factors associated with reduced visual performance due to glare. They also found that, if properly positioned, the IOL type was not a factor. A case report[15] of a 58-year-old airline pilot with glare, monocular diplopia, and halos at night revealed that all of the visual symptoms were due to the 4 positioning holes and 2 staking holes in the optic of the IOL. When the IOL was exchanged for a lens with no positioning holes, the pilot attained 20/15 vision, with none of his previous symptoms, and was able to resume flying.

The rates of surgically ruptured posterior capsules, transiently elevated intraocular pressure, and inflammation were within the acceptable standards.[3, 4, 10] The rates of persistent uveitis, chronic glaucoma, vitreous hemorrhage, and epiretinal membrane seem high, but all occurred in a single flyer. An anterior chamber IOL did require repositioning, a not uncommon complication with these IOLs.[4] The retinal hole, noted in 1 aviator postoperatively, may or may not have been related to the surgery. It received surrounding laser photocoagulation, and the flyer was returned to flying duties after 1 year's observation.

Several special aeromedical considerations pertain to aviators with IOLs. The first concerns etiology. Are aviators at more risk of developing cataracts? Although theoretically proposed, clinical epidemiological data to support lens damage caused by ambient sunlight is weak. The best study to date was a recent retrospective one on Maryland watermen.[16] It showed that only cortical changes in the lens correlated with lengthy sunlight exposure. Additionally, it is still unclear what degree of protection is required after cataract surgery. Other aeromedical considerations include anisometropia, unusual residual refractive errors, mon-ocular diplopia, glare, and high presbyopia. They can be causes for serious concern and might result in denial of flying status or limitation of aircraft assignment.

Some military aviators (FAR-type) are exposed to high acceleration forces ($+G_z$) and concern regarding the displacement of intraocular lenses was investigated. PMMA intraocular lenses weigh approximately 10 mg. The human lens increases in weight from 140 mg, at 1 year of age, to 250 mg, at 80 years.[17]

While no studies have been done to determine whether the human lens decenters under $+G_z$ forces, visual acuity has been tested, in humans, up to 9 $+G_z$'s and remains remarkably good. Thus, if properly fixed within a lens capsule that has not sustained significant zonular rupture, it is reasonable to expect that the IOL will be maintained in a central, steady position. USAFSAM performed a centrifuge study (unpublished) on 17 rheaus monkeys in 1981-2. Each of the monkeys was evaluated and underwent bilateral cataract surgery with placement of an anterior chamber, iris-supported, or posterior chamber IOL. At 8 to 9 months post surgery, they were each subjected to up to 10 $+G_z$. Post-centrifuge slit-lamp reexamination confirmed that no lens was displaced. (Verbal communication - Onex D. Steverson M.D., Thomas J. Tredici M.D., and Col. Douglas J. Ivan M.D.)

This initial report of our prospective study has some shortcomings. The sample size is only 23 and is too small for statistically significant comparisons. Second, our sample population of flyers are a young and healthy group, usually without other medical or visual problems. Third, there is no age-matched, non-flying control group, so the aviators have been compared to the general population receiving the same surgery. Fourth, we are not aware of any data on a hypothetical group of flyers that might have had surgery with an IOL, but had complications, and were not referred to USAFSAM for evaluation and waiver consideration.

Fifth, we cannot be certain that all subjective symptoms are being reported, as military aviators are usually highly motivated to remain on flying status. Finally, follow-up has not been sufficiently long to detect all late complications or to learn about the difficulties encountered in the flying environment. In our study, 44% of the aviators had only one evaluation because most of them have only recently been evaluated.

Based on current technology, USAFSAM recommends that flyers, with cataracts clinically requiring surgery, receive extracapsular cataract extraction and a posterior chamber IOL, if possible, because of the lower associated complication rates with the ECCE/PC-IOL method. The IOL should be a 7 or 6 mm PMMA lens with ultraviolet (UV) protection, but without positioning holes in the optic. Silicone and multifocal IOL's cannot be recommended, at this time. The visual standards required for a return to flying duties include the following: 20/20 or better best-corrected distance and near visual acuity; pass all other screening performance tests, e.g. stereopsis; no subjective problems such as glare, halos, or difficulty with bifocals/trifocals, anisometropia, etc.

After the initial USAFSAM evaluation, follow-up evaluations at USAFSAM should occur at least every 1 to 2 years. It should take 10 to 15 years to obtain a sample population of 75 to 100 aviators. A group this size is necessary for determining the predictive value of eye tests, the evaluation of new tests, and for statistical analysis.

Currently, USAFSAM recommends a return to flying duties, with no aircraft restriclights, when his pupils dilated in the dark. Because this effect was monocular, he reported that he was able to ignore this distraction.

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Currently, USAFSAM recommends a return to flying duties, with no aircraft restrictions, for flyers with a monocular IOL who meet the visual standards. Bilateral IOL's are more controversial, but it is likely that, if all visual tests are normal, an aviator with bilateral IOLs will also be granted a waiver, without restriction as to aircraft type.

In summary, USAFSAM has evaluated 23 flyers who have had cataract surgery with an IOL. Twenty-two (96%) flyers were deemed visually qualified to return to flying duties, although two were disqualified for cardiac reasons. Eight flyers have safely flown since surgery. Although follow-up is short, the initial data are encouraging. As our study progresses, further reports on this very unique and interesting group will be presented.

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L'INTEGRATION SPATIALE VISUELLE PAR LE TEST DE SENSIBILITE AUX CONTRASTES CHEZ LES OPERES DE CHIRURGIE REFRACTIVE

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RESUME -

La chirurgie réfractive permet la plupart du temps une correction satisfaisante des vices de réfraction. Néanmoins, cette technique entraîne des conséquences fonctionnelles à court et moyen terme. Une complication moins étudiée mais primordiale est le dommage apporté à la capacité d'analyse spectrale du système visuel. Nous avons pu observer 112 opérés de kératotomie radiaire chez qui, nous avons analysé l'intégration spatiale visuelle par le test de sensibilité aux contrastes à stimulation polychrome. Nous avons constaté une atteinte systématique dans la reconnaissance des basses fréquences spatiales chez les opérés dont la cicatrisation n'était pas terminée. Ceci correspond à une difficulté de l'analyse des détails grossiers d'une scène visuelle. Et, lorsque le pilote vole à grande vitesse et basse altitude, ce sont les seuls éléments visuels qu'il est capable de prendre en compte. Nous avons étudié la validité du test comme marqueur de cicatrisation post-opératoire.

INTRODUCTION -

La micro-chirurgie de la cornée, en vue de corriger des vices de réfraction optique (myopie, hypermétropie, astigmatisme) pose actuellement certaines difficultés d'expertise aux ophtalmologistes experts en Médecine Aéronautique. Le principe commun de ce type d'intervention est de modifier le pouvoir dioptrique de la cornée en changeant sa courbure antérieure. En matière d'aptitude, nous ne statuons la plupart du temps que sur des sujets opérés de kératotomie radiaire. En effet, l'importance de l'amétropie dans les autres cas entraîne des désordres anatomiques d'exclusion.

Nous savons les désordres fonctionnels induits par cette chirurgie :
- Acuité visuelle variable pendant plusieurs mois, réfraction évolutive vers l'hypermétropie ;
- Trouble de la résistance aux hautes luminances que nous avons montré par ailleurs. Les modifications ont lieu jusqu'à une année post-opératoire, voir jusqu'à 3 ans pour certains ;
- Processus cicatriciel variable selon les individus pouvant se prolonger jusqu'à 5 ans et plus.

Un autre facteur important à prendre en compte chez un navigant : est celui du transfert du spectre électromagnétique à travers la cornée remaniée par les cicatrisations. On peut se demander en effet, si la qualité du message visuel n'est pas altérée par les déformations caractéristiques de la kératotomie radiaire. Enfin, puisqu'il n'existe pas de tests fonctionnels permettant de juger de la consolidation structurelle cicatricielle cornéenne, l'analyse du transfert pourrait être une approche intéressante par l'évolution puis la stabilisation des résultats.

MATERIELS ET METHODES -

112 candidats, à une spécialité de navigant, opérés de kératotomie radiaire ont été suivis tous les 6 mois pendant 4 ans après l'intervention. Il s'agissait de sujets dont les résultats fonctionnels basés sur les examens classiques étaient très satisfaisants : Acuité visuelle entre 9 et 10/10 ; réfraction comprise entre + 1 et - 1 dioptrie ; champ visuel central normal au périmètre automatisé HUMPHREY. Nous ne tenons pas compte dans cette étude des mesures de la résistance à l'éblouissement.

A été analysée l'intégration spatiale visuelle par le test de sensibilité aux contrastes à stimulation polychrome. L'examen est basé sur le fait que le système visuel fonctionne en analyseurs fréquentiels du spectre électromagnétique grâce aux propriétés particulières des champs recepteurs situés dans les cellules ganglionnaires : Les cellules (X) sont au centre de la rétine, à résolution spatiale élevée, à résolution temporelle faible, qui analysent les contrastes spatiaux donc les formes. Elles sont spécialisées dans la réception des hautes fréquences spatiales, des détails fins. Les autres (cellules Y) en périphérie de la rétine, détectent le mouvement, analysent la caractéristique temporelle du stimulus. Elles receptionnent les basses et moyennes fréquences spatiales, les détails moyens ou grossiers. D'autres encore (cellules W) ont des propriétés appartenant aux cellules X et Y ; mais les caractéristiques précises ne sont pas encore élucidées.

Nous savons qu'il existe des canaux de réception et de transmission spécifiques à chaque fréquence spatiale. Ainsi, l'activation cellulaire est différente en fonction de la composition spectrale de l'image ou en fonction des modifications du transfert spectral à travers le dioptre oculaire.

Pour analyser cette propriété, nous utilisons des réseaux sinusoïdaux stationnaires rouge de coordonnées trichromatiques (x = 0,665 ; y = 0,305), vert de coordonnées trichromatiques (x = 0,365 ; y = 0,557), bleu de coordonnées trichromatiques (x = 0,142 ; y = 0,071) générés par un calculateur. Ils sont présentés sur un moniteur couleur haute résolution. On fait varier le contraste et la fréquence spatiale de l'image de stimulation, de même que son orientation (verticale ou horizontale) pour obtenir une réponse élective des différents champs recepteurs ganglionnaires rétiniens. Les mesures sont effectuées pour chaque modalité de contraste allant de 0 à 1 et de fréquence spatiale dans l'ordre suivant : 0 ; 0,14 ; 0,27 ; 0,57 ; 1,16 ; 2,38 ; 4,75 ; 6,35 ; 9,51 cycle par degré d'angle visuel. La luminance de l'environnement est de couleur blanche (x = 0,35 ; y = 0,38) isoénergétiques sur toutes les longueurs d'ondes. L'examen explore donc l'oeil comme l'audiogramme explore la valeur fonctionnelle auditive. Les gains et déficits par rapport à chaque fréquence spatiale se mesurent en décibels.

RESULTATS -

Les résultats ont été analysés en fonction des réponses dans les basses, moyennes et hautes fréquences spatiales en stimulation horizontale et verticale.

- Chez les 112 sujets (216 yeux), les réponses en stimulation verticale et horizontale dans les trois gammes de luminance colorée sont normales dans les fréquences moyennes entre 1,16 et 4,75 cycles/degré.

- Chez 23 sujets (45 yeux), les réponses dans les basses fréquences, entre 0,14 et 0,57 cycles/degré, en horizontale et en verticale pour une stimulation rouge sont diminuées de 2 décibels en moyenne mais restent cependant dans les limites de la normalité.

- Chez 89 sujets (160 yeux), les réponses sont normales dans les basses fréquences quelles que soient la stimulation et la chromaticité de la stimulation.

- Chez 90 sujets (175 yeux), les réponses dans les hautes fréquences, entre 4,75 et 9,51 cycles/degré, sont normales quelle que soit la stimulation.

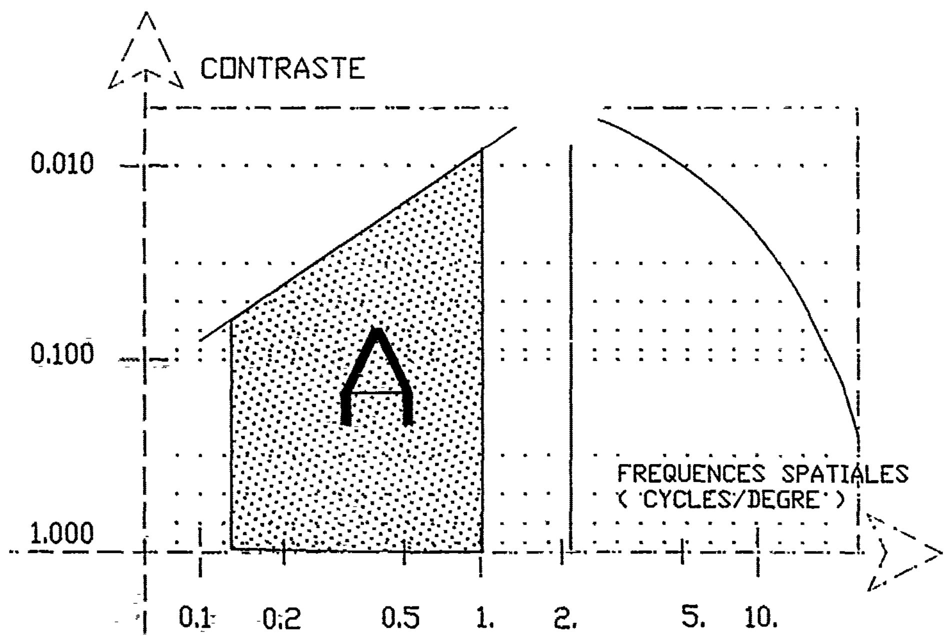
- Chez 22 sujets (41 yeux), les réponses dans les hautes fréquences sont diminuées dans les limites inférieures de la normalité pour les trois stimulations colorées et quelle que soit l'orientation.

Le déficit observé dans les réponses en basses fréquences sous stimulation rouge par rapport à la moyenne des réponses des sujets examinés s'accompagnait d'un état anatomique non consolidé à l'examen biomicroscopique. Les incisions étaient encore larges, le bouchon épithélial en place. Par contre, les patients sans anomalie de transmission montraient des traits radiaires estompés sans bouchon épithélial. Nous nous sommes alors demandés si ce trouble localisé dans les basses fréquences pouvait être un critère fonctionnel d'évolutivité cicatricielle. En effet, la kératotomie radiaire engendre un tissu cicatriciel radiaire paracentral avec réaction discrètement oedémateuse du stroma cornéen. Cet état induirait un oedème léger de la portion centrale par augmentation des espaces entre les fibres de collagène. De ce fait, une modification de la transmission du message lumineux s'observerait jusqu'à la diminution de l'oedème, donc jusqu'à la consolidation cicatricielle.

Pour le confirmer, nous avons calculé un score correspondant au domaine de visibilité sous la courbe d'intégration spatiale visuelle, dans les fréquences comprises entre 0,14 et 1,16 cycles/degré. Nous avons cherché les modifications de ce score en fonction du temps post-opératoire (certains sujets ayant eu des examens avant intervention).

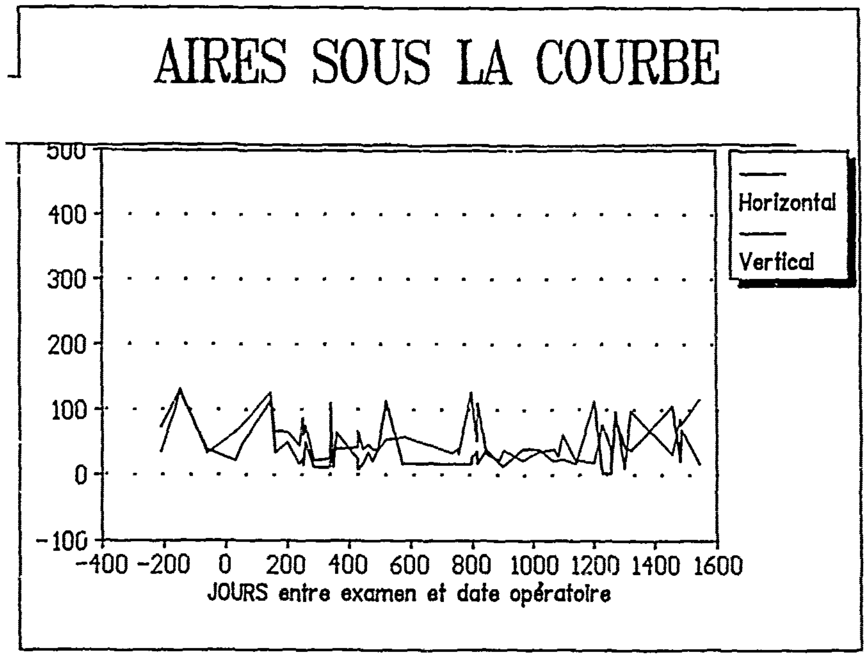
Le calcul du score (A) s'est fait suivant la formule suivante :

$$A = \log(C1)\,(f2-f1) + \frac{\log(C2)-\log(C1)}{\log(f2)-\log(f1)}\,(f2(\log(f2)-1)-f1(\log(f1)-1))$$



C1 = valeur limite du contraste pour la fréquence 0,14
C2 = valeur limite du contraste pour la fréquence 1,16
f1 = fréquence 0,14
f2 = fréquence 1,16

Nous avons obtenu l'établissement d'un résultat chiffré qui dans les examens successifs post-opératoires n'a pas montré de tendance positive ou négative, comme le montre la figure ci-dessous :



DISCUSSION -

Ainsi pour nos observations, toutes les réponses aux stimulations fréquentielles, basses et moyennes, sont dans les limites de la normalité. Seules les hautes fréquences sont altérées de manière marquante. A noter que ce dernier groupe de sujets possède les mêmes caractéristiques de réfraction : hypermétropie de + 1 dioptrie, acuité visuelle soit de 9/10, soit de 10/10. Ceci confirme l'influence des amétropies sur la zone des hautes fréquences spatiales.

Plusieurs réflexions sont évoquées en ce qui concerne l'étude des basses fréquences : Soit le mode de calcul utilisé est trop grossier et ne permet pas de prendre en compte les variations moyennes de 2 décibels qui devaient valider la première hypothèse ; Soit les résultats obtenus à partir de la fonction de sensibilité aux contrastes sont trop approximatifs ; soit et c'est le plus probable, l'entité histologique représentée par la cornée centrale n'est pas suffisamment remaniée en post-opératoire pour entrainer une perturbation fonctionnelle notable.

Par contre, la corrélation entre une hypermétropie de + 1 dioptrie et l'atteinte constatée dans les hautes fréquences confirment nos premiers travaux(1): ils permettent de prévoir une évolution hypermétropique dommageable pour le parcours d'accommodation du futur navigant.

CONCLUSION -

La technique de kératotomie radiaire ne semble pas modifier la transmission centrale du spectre électromagnétique. L'analyse de l'intégration spatiale visuelle centrale à partir du test de sensibilité aux contrastes à stimulation polychrome ne peut être actuellement une référence pour juger d'une consolidation de chirurgie réfractive par kératotomie radiaire. Il convient maintenant d'effectuer une analyse fréquentielle et polychrome plus sélective pour dégager un éventuel marqueur d'évolutivité de la cicatrisation cornéenne si la sensibilité actuelle de la méthode le permet. Ceci devant être couplé avec une augmentation de taille du champ de stimulation et une excentricité de cette stimulation. Cependant, le test montre des résultats intéressants dans l'étude des hautes fréquences en pronostiquant l'évolution au long cours vers une hypermétropisation.

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CONTRAST SENSITIVITY & GLARE FOLLOWING KERATOTOMY

by

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SUMMERY:

During the later years radial keratotomy has been proposed as a posibility for young myops to obtain adequate visual acuity to fulfil the visual requirements for military pilot.
Post keratotomy applicants are never the less not usually accepted as pilots, due to reports describing reduced visual functions, increaced sensitivity to glare, and unstable refraction following keratotomy.
With the purpose to evaluate the visual problems following keratotomy, a number of postkeratotomy applicants has been refered to the eye-clinic at the Department of Aviation Medicine for extended eye-examination.

Refraction was stable in all eyes but one. The visual functions at low illumination was reduced in one third of the eyes, and more than half of the eyes had reduced contrast sensibility during radial glare.

It is generally adviced not to accept postkeratotomy patients as pilots. Demonstrated stability of refraction and acceptable visual function during glare and at reduced illumination should be regarded as mininum requirement, if a postkeratotomy patients is to be acceptet as an aviator.

INTRODUCTION:

Good visual acuity is mandatory for pilots and other aircrew members.
Reduced visual acuity is mostly caused by refractive errors as myopia or astigmatism. Refractive errors are usally corrected by glasses or by contact lenses without major problems.
In some jobs such as highway patrolmen, and high performance pilots, use of spectacles and contact lenses are impractical or impossible.

Applicants, who do not possess adequate visual acui / without correction, are then usually rejected from these jobs.
During the latest six to eight years refractive surgery has been introduced as an alternative to traditional correction.

A lot of young myops then have gained the hope of obtaining adequate vision to fulfil the criteria for getting a job as professional pilot.

By keratotomy the refractive power of the cornea is changed by placing cuts into the corneal stroma.
The central part of the cornea is left unaffected by the cuts.
The corneal stroma is weakened in its periphery by the cuts, resulting in a secundary flatening of the central part of the cornea.
Since the central cornea plays the lions part of the corneal refraction - keratotomy will result in a decrease of the optical power and consequently a reduction of the myopia.

A Keratotomy is easy to perform. In most cases the desired optical correction is achieved and the complications are few. Still it must be remembered that keratotomy represent surgery on a healthy eye.

Eventhough the keratotomy in most cases must be regarded as successful, there seems to be postoperative visual problems at least in some patients.(1,2)
In a number of patients visual acuity is reduced by one or two Snellen fractions (1). The reason for this is a reduction in optical quality of the corneal refraction due to increased sphaerical aberation and the formation of scars.
Instability of refraction may be seen even years after surgery.

In nearly all patients contrast sensibility is reduced and some patients complains of increasing sensitivity to glare. (2)

Due to these observations the danish civil aviation administration had decided to extend the visual standard examinations by tests for glare and contrast sensitivity in all applicants, in whom keratotomy had been performed.
As consequence of this decision a number of subjects has been referred to the eye clinic at the Department of Aviation Medicine for extented eyeexamination following keratotomy.
This paper pressent the results of these examinations.

MATERIAL:

23 persons, of the age 22 - 43 years, have been examined. All patients were refered to examination because of a wish to obtaine either an aviators licens or to join the police forces. Of the tested persons, 3 had only been operated on one eye, while the rest have had surgery in both eyes.
6 persons were operated in Moscow - 7 in United States and the rest in Denmark.

I 20 eyes the diameter of the central optical zone, uneffected by scars produced by the keratotomy, was equal to or less than 3 mm.

The number of cuts in each cornea varied greatly as demonstrated in table 1.

Corneal cuts:	4	6	8	12	16	24
No of Eyes :	8	6	16	6	6	1

Table 1: Number of corneal cuts in 43 myopic eyes operated by radial keratotomy.

In none of the patients, operative or postoperative complications were described.

The examinations were performed 10 to 37 month after surgery.

METHOD:

As well the glare test as the test for contrast sensitivity was performed acording to the describtion by Aulhorn (3). Landolt rings of a size comparred to 6/24 objects were presented as test symbols at stepwise reduced contrast levels.
The test result was the lowest contrast level at which the test subjects could identify the test symbol.
Normal values for the test system have been presented by Aulhorn - We have comfirmed the results in a test of 50 young pilot applicants.
The normal values are indicated by a dashed line on the following figures.
Constrast sensitivity was tested at low luminans at 2 different levels of background luminance (0.1 and 0.03 cd/m^2) and during radial glare.

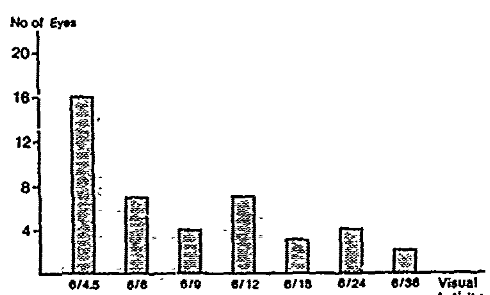

Figure 1: Uncorrected Visual Acuity in 43 Eyes after Keratotomy

RESULTS:

Postoperative 27 eyes had visual acuity of 6/9 or better without corretion (Figure 1) and in all but one eye visual acuity was 6/6 or better with optimal correction.

Preoperative myopia ranged between 1.5 and 7 dioptre.
In all eyes the myopia was reduced by the operation but in 6 eyes the residual myopia exceeded 3 dioptre (Figure 2).

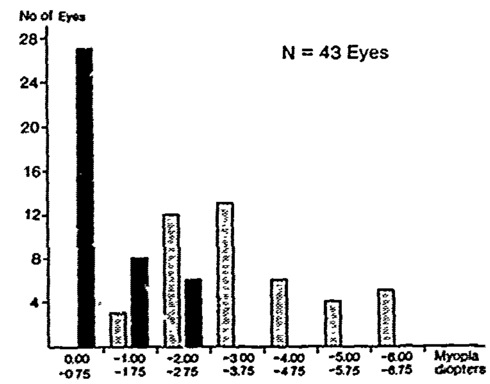

Figure 2:

Myopia (in diopters) before (▨) and after (■) Keratotomy

Fluctuating refraction was observed in 4 eyes, all with 16 or more corneal cuts. The change in refractive power ranged between 0.5 and 0.75 dioptre.

Figure 3. presents contrast sensitivity messured at a background luminance of 0.1 cd/m^2.
The contrast sensitivity was reduced in most of the eyes but only in 6 eyes the values were outside the normal range.

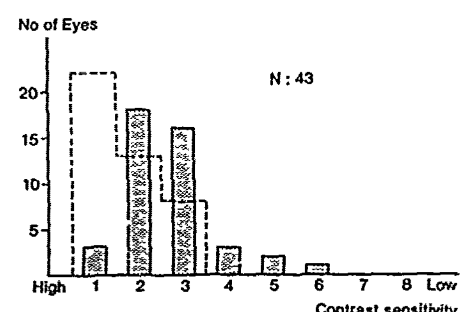

Figure 3:

Contrast sensitivity at low illumination. (Background luminans 0.1 cd/m^2) 43 eyes following radial keratotomy (Standard range ——)

These results were confirmed by the test at the 0.03 cd/m^2 luminance level. The majority of the eyes had reduced contrast sensitivity, but in only 7 eyes the test result was patological beyond any doubt. Five of these eyes were characterized by a preoperative myopia of at least 5 dioptre.

The number of corneal cuts greatly affected the postoperative contrast sensitivity (figure 4). Only one eye with less than 12 corneal cuts had patological reduced nesoptic readings.

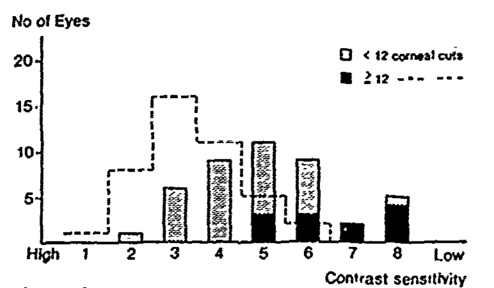

Figure 4:

Contrast sensitivity at low illumination. (Background luminans 0.03 cd/m²)
43 eyes following radial keratomy (Standard range ——)
Eyes with more (■) or less (□) than 12 corneal cuts.

Allso the size of the central optical zone seemed to be of some importance for the devellopment of reduced contrast sensitivity.

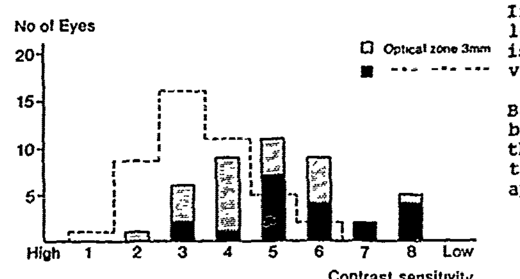

Figure 5:

Contrast sensitivity at low illumination. (Background luminans 0.03 cd/m²)
43 eyes following radial keratomy (Standard range ——)
Central optical zone less than 3mm (■) - Optical zone more than 3mm (□)

Only two of the tested individuals complained of glare.
From the test results it is obvious, that contrast sensitivity during glare was reduced in the majority of eyes.
The sensitivity to glare was primary connected to the size of the central optical zone (figure 6).
All eyes with an optical zone of 3.5 mm or more had normal glare test.

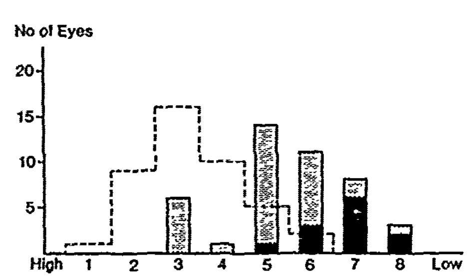

Figure 6:

Contrast sensitivity during radial glare.
43 eyes following radial keratomy (Standard range ——)
Eyes wiyh more (■) or less (□) than 12 corneal cuts.

Three of the patients had only been operated on one eye.
All three applicants had normal contrast sensitivity in the unoperated eye but in two cases severely reduced contrast sensitivity in the operated eye.

Three patients were retested 6 to 12 month after the primary test.
In two patient contrast sensitivity was unchanged, but in one person the result of the examination had slightly improved.

DISCUSSION:

The presented study clearly indicates, that radial keratotomy may result in increased sensitivity to glare and reduced visual function at low illumination. These observations are in agreement with the results found by other investigators (1,2).
The significanse of the reduced contrast sensitivity is still a matter of discussion (1,2,4)

The propability of reduced postoperative visual function is increased by the number of corneal cuts and by reduction of the unaffected central corneal zone.
If the number of cuts are equal to or less than 8, and the central optical zone is 3.5 mm or more, the reduction of the visual function is usally insignificant.

Based on the litterature and supported by the results of the present study, the danish aviation autorities has stated the following policy on post keratotomy applicants for pilot licening.

A. Royal danish airforce:
Post keratotomy applicants are not accepted.

B. Commercial pilot (Civil):
Post keratotomy applicants are accepted one year postoperative if:

1. -preoperative refractive error was equal to or less than +/- 5 dioptre.
2. -postoperative refractive error is equal to or less than +/- 3 dioptre.
3. -postoperative visual acuity using optimal correction is 6/6 or more.
4. -postoperative visual acuity is 6/9 or better at repeated examinations using prescribed correction.
5. -contrast sensitivity at low illumination and during glare are acceptable (= not reduced beyond normal for persons 60 years of age).

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A survey of Colour Discrimination in German Ophthalmologists: changes associated with the use of lasers and operating microscopes.

by

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Abstract: colour vision tests were performed on 211 German ophthalmologists during their annual meeting at Essen. The subjects also filled in detailed questionnaires about their use of lasers and operating microscopes, and their ocular and general health. It was found that compared to those doctors who do not use lasers or operating microscopes, 33% of those who do have decreased colour discrimination, for colours in a tritan colour-confusion axis (>2SD above normal). There is a relationship between number of patients treated and the degree of threshold elevation. 30 hours of use of the operating microscope produces an increase in tritan threshold equivalent to 1 panretinal photocoagulation. After treating between 1000-10000 patients with Argon lasers, the average colour threshold will be > 2SD above the normal mean. There is an important additional source of variation of colour vision in surgeons who use lasers, due to a factor which apparently offers protection against light hazard.

INTRODUCTION

Arden, Gunduz and Perry[1] recently described a new method of testing colour vision. They produced images of varying colour-contrast on a TV monitor. They provided evidence that the system was capable of detecting changes so small that they were below the threshold for other commonly employed tests. Moreover the deviations from normal could be measured in a quantitative fashion. One of the serendipitous findings was that the use of Argon blue-green lasers caused a rise in colour thresholds, which lasted for several hours[2], and subsequent work showed that in addition there was a chronic effect so that after several years of using lasers for pan- retinal photocoagulation, the ophthalmologist's threshold for colour contrast along a tritan confusion axis was elevated for a considerable time, perhaps permanently. This work was done on a small sample (17 surgeons) and obviously a larger survey was indicated[3]. This was carried out at the 1990 Essen meeting of the German Ophthalmological Society.

METHODOLOGY

The computer-graphics technique originally described was used. It was modified from the description given in [3]. The colours were displayed on monitors with a 90Hz refresh rate, and dot-pitch of 0.31 mm, with a 960 x 640 pixel resolution (non interlaced). The software included new calibration routines, so that the calculations of screen colours and luminances were based upon look-up tables provided by direct measurement. The new monitors required different "graphics engines" and a 100 MHz card, based on the Hitachi ACRTC chip set with single pixel scrolling, pan and zoom facilities and foreground/background display with alternate screens was chosen. It was used with a Brooktree "24-bit" palette. The software was rewritten in 'C' for use in a PC, using an 80286 CPU with an 80287 mathematical co-processor. instead of presenting a grating, the software presented an alphabetic letter, and the subject's task was to read it correctly. Contrast was varied according to a Modified Binary Search paridigm (4). The tester watched the screen of the PC, where the correct letter was displayed, together with the current contrast, and the means and standard deviations of the peaks and the troughs. Threshold was determined to within 0.3%, which is the limit for the precision of the analogue to digital converter system and the software[1]. The use of letters speeded up the threshold determination and removed any subjective aspect. The appearance of the letters was for 200 msec every second, in the centre of a large uniform constant field. To save time, only one eye of a subject was tested. The relative luminance of the red: green and blue: green guns was determined by heterochromatic flicker photometry, and then colour contrast thresholds were measured in protan and tritan colour confusion axes, which were orthogonal to each other in CIE color space. Two sets of equipment were used, one from Munich, and one from London. For technical reasons, the flicker values were different for the two sets, but the software made allowance for this, and some subjects were tested on both machines to determine if the same thresholds were found by each instrument, and this was the case.

Additional tests: All subjects were refracted on an autorefractor, and their visual acuity determined. Any person whose colour threshold was above normal or acuity was below 1.0 was examined on a scanning laser ophthalmoscope, as were persons who had any eye disease.

Subjects: These were all German ophthalmologists, attending a 4 day training and scientific meeting. Repeated announcements from the chair emphasised that we wished to test not only those who used lasers, but those who did not, and we also wished to see ophthalmologists who were heavy users of operating microscopes, but who did not use lasers, and more elderly ophthalmologists who did not use any such equipment. In this way, we were able to obtain control groups.

Questionnaires: Every person tested was asked to fill in a detailed account of his/her use of Argon blue green lasers, other lasers (specifying which) and the hours spent operating with a microscope. The use in each year was entered separately. There were detailed questions about any congenital colour vision defect, and about general health and any eye disease.

Exclusions: These were determined prior to the survey and included anyone with systemic disease, known eye disease, reduced visual acuity, abnormal fundal appearance, or in whom age or laser use was not specified. In addition, we eliminated several persons with special experience. Thus, several had perfected their technique with the Xenon photocoagulator, and transferred later to Argon (" I do not get flashbacks" !), and one subject who pioneered the use of Argon had, as a precaution, always used yellow filters.

RESULTS

Normal values.

42 subjects had no exclusion criterion, no laser and no operating microscope experience, but were in ophthalmological practice. The results obtained are plotted against age in figs1 & 2.

It can be seen that the modulation thresholds are slightly higher for the tritan colours, but are tightly and symmetrically distributed around the mean. In accordance with the previously published results, there is little change of threshold with age ranging from the age of qualifying to that of retirement. This group was enlarged to 62 by the inclusion of other doctors who had treated fewer than 100 patients with lasers (the average figure was 28), & had less than 100 hours of operating experience in the last 3 years. This was not sufficient to change the colour thresholds. The regression equations given in the figure captions were calculated for this group. The slope of the least squares line is not significantly different from 0. The dotted lines in the graphs show the upper limit of normal (mean +2SDs). These results make it most unlikely that the relationship between number of patients treated and visual performance shown below due to the increasing age of the more experienced surgeon.

Laser users and non laser users compared.

Figure 3 shows the interval distribution of thresholds in laser and non laser users. It is evident that for protan colours, the laser makes little difference, but that the distribution of tritan thresholds is strongly skewed for the laser-users only.

The relationship between age and threshold for 189 laser users is shown in figures 4 and 5: although the values are higher than for the non- laser users, there is no evident age relationship, as indicated by the regression analysis. However, 32 % of the laser users have tritan thresholds more than 2 standard deviations above the age-corrected mean value for their colleagues.

Laser use in the last 3 years

Some of the ophthalmologists had ceased to use lasers several years ago, and the total number of patients treated was often hard to estimate. Therefore we analysed the results of the last 3 years use, shown in table 1.

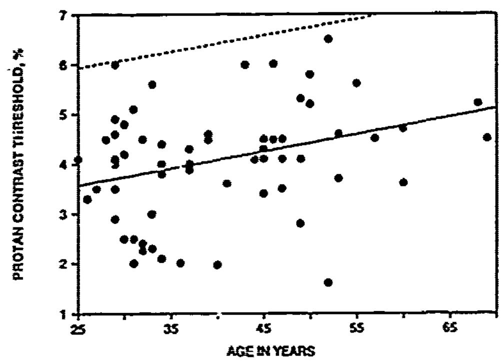

Figure 1. Relationship of protan colour contrast threshold to age in 42 ophthalmologists who do not use lasers or operating microscopes. The dashed line is the mean regression line for these observers and 20 others who had treated fewer than 100 patients. The regression equation is Threshold = 2.99 + 0.247 x age. The correlation coefficient r= 0.22. The slope of the regression line is not significantly different to zero. The dotted line shows the expected upper limit of normal. In this and other figures, solid circles are used to show protan thresholds.

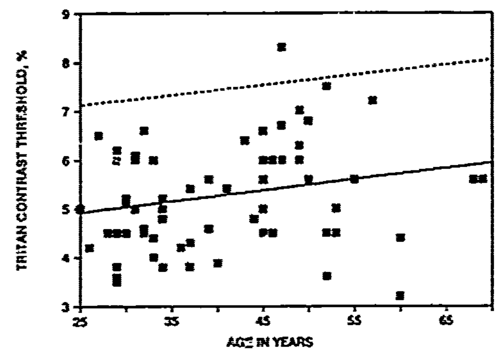

Figure 2. Rel[illegible] of tritan colour contrast threshold to age in 42 ophthalmolo[illegible] not use lasers or operating microscopes. The dashed [illegible] ean regression line for these observers and 20 others whose [illegible] treated less than 100 patients. The regression equation is Thre[illegible] = 4.38+ 0.022 x age. r= 0.22 The slope of the regression line is no[illegible] significantly different to zero. The dotted line shows the expected upper limit of normal. In this and other figures, solid squares show tritan thresholds.

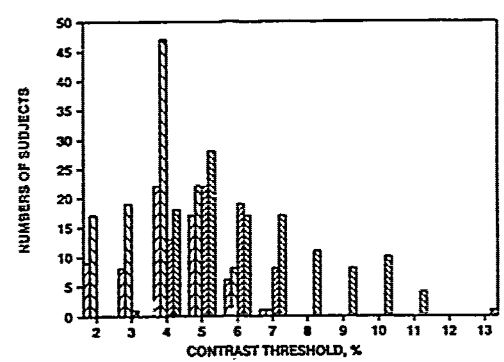

Figure 3. Interval histogram for protan and tritan colour thresholds of users of lasers compared to non-laser users. The protan results are broad-hatched, and the tritan results narrow-hatched. Hatching lines drawn upward to the right indicate non-laser users, hatching lines downward to the right indicate laser users. Only tritan laser users' results are skewed.

Table 1

Changes in Thresholds with laser usage in the last three years

patients treated	None	<100	100-400	400-800	800-1600	1600-4000
number	59	17	32	35	23	10
mean age	42	33	38	41	42	41
Protan*	4.21 ±.14	3.41 ±.24	3.94 ±.16	3.66 ±.22	4.02 ±.17	3.61 ±.36
Tritan*	5.49 ±.15	5.42 ±.37	5.48 ±.26	6.84 ±.38	7.16 ±.50	7.32 ±.42
T::P ratio	1.40 ±.07	1.68 ±.12	1.44 ±.08	2.0 ±.17	1.83 ±.12	2.19 ±.20

* mean threshold with standard deviation

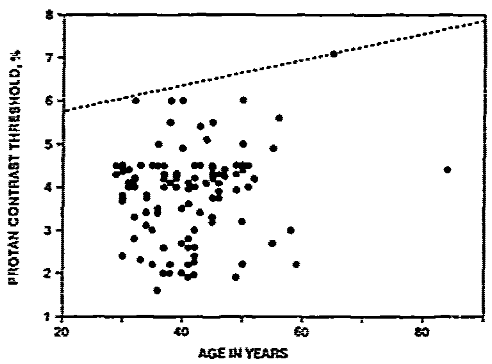

Figure 4. Relationship of protan colour contrast threshold to age in 117 ophthalmologists who use lasers and operating microscopes and have treated more than 100 patients. The regression equation is Threshold = 3.22+ 0.0155 x age.The correlation coefficient r = 0.11 The slope of the regression equation is not significantly different to zero. The dotted line is the upper limit of normal from figure 1.

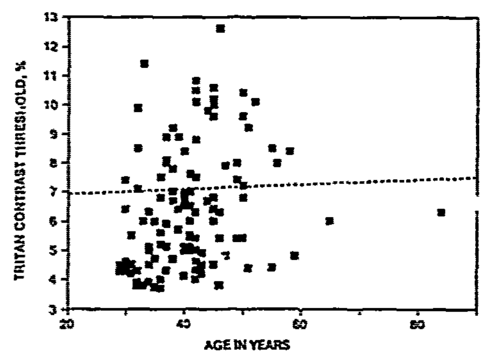

Figure 5.Relationship of tritan colour contrast threshold to age in 117 ophthalmologists who use lasers and operating microscopes and have treated more than 100 patients. The regression equation is Threshold = 4.21 + 0.055 x age. r= 0.22. The slope of the equation is not significantly different to zero. The dotted line shows the expected upper limit of normal from figure 2. Note that 37 persons are above the upper limit of normal, despite the lack of correlation with age.

There is a clear relationship between degree of use and threshold elevation. Note that the mean age of the non-laser using group is similar to those who use lasers heavily. Those entering the ranks of the laser users seem on the whole to have lower thresholds. The effect of laser use is disproportionate for tritan values, and this can best be seen by taking the ratio tritan: protan threshold. Figures 6 and 7 show the protan and tritan thresholds of individuals plotted against number of patients treated. These vary greatly, and for ease of presentation, the X- axis is logarithmic. It can be seen that there is a trend, and the least squares fit to the data shows that the slope of the log-linear regression is highly significant for tritan thresholds. A similar relationship was found if only the last 3 years of laser use is considered. However there must be other sources of variance, since the correlation coefficient is relatively low. For this reason we divided the subjects into 2 groups, those who only used lasers and those who used lasers and operating microscopes. Fig 8 shows that some of the higher values are seen in doctors who have low laser experience but who use the operating microscope extensively. Figures 9 and 10 show graphically the relationship between total hours spent operating (it was not possible to determine how many hours were spent using a microscope) and the colour thresholds. It appears that there is an increase in both protan and tritan thresholds, with increased operating. Note that protan thresholds are unchanged with the number of patients who are treated with a laser, and the correlations between tritan threshold and laser use are better than between tritan threshold and microscope use. Therefore, although there must be overlap between the effects of lasers and microscopes (since surgeons as a whole use both, and the total use increases with age), it is likely that an additional effect occurs with the incandescent light of microscopes which additionally affects protan vision.

In order to determine whether these two factors were synergistic, we analysed the significance of total exposure to light, giving various weighting to operating. The results are shown in figure 11. The X axis gives the relative weight ascribed to one hour of operating, with the value of 1 pan-retinal photocoagulation being unity. The vertical axis is derived from the regression of tritan threshold on the logarithm of this " total exposure", using data on surgeons who had treated over 100 patients. The graph shows the regression coefficient, and the normalised ratio of the slope of the regression line divided by the variability of the slope. For both measures, there is an obvious maximum, such that the best fit is when 30 hours of operating are taken as equivalent to 1 patient lasered. A similar analysis was performed with the exposure to the last 3 years only, or the last 3 years operating combined with total career laser use. The highest correlation coefficients obtained were for exposure over the entire career. There are no significant correlations to be found with age, or between threshold elevation and the change in the heterochromatic flicker values. The results of log linear and linear analysis for number of patients/ elevation of threshold are essentially similar, in that a significant positive slope is found. The results all indicate that there is some other variable which influences colour threshold, apart from exposure to light. One possibility, which is raised by the apparent linear relationship between threshold and log number of patients (fig 7) is that the rate of change of threshold decreases as the number of patients treated increases. For this reason, linear/linear and log/linear analyses were carried out. For the entire sample of 189 laser users, the intercept values of Y are not significantly different, and the values of the correlation coefficient are very similar (.3370 for linear analysis and .3418 for log linear analysis). The slopes of the regression lines are of course different, but the ratio of slope to its standard error is also similar (4.84 compared to 5.22). It is not possible to decide which relationship represents the data best. If the logarithmic relationship were to be true, it would imply the presence of a maximum effective elevation of threshold, no matter how active the surgeon.

Analysis by sex: 44 of the sample were women, and of these 18 used lasers. The mean age of the 18 was lower than for the female group as a whole. The thresholds for non- laser users were the same as those of the men. The small group of female laser users had on average treated many fewer patients than their male colleagues: the average tritan threshold was only mildly elevated with respect to ther non-laser using counterpar. The protan thresholds for the 18 were lower than for the remaining female group.

Exclusions.

The congenital colour deficiencies show elevations in the protan axis rather than the tritan (some of the anomalies seen were deutan, but this was not specifically tested for). By contrast, persons with systemic diseases have tritan elevations. These are of the same order as those associated with the use of lasers.

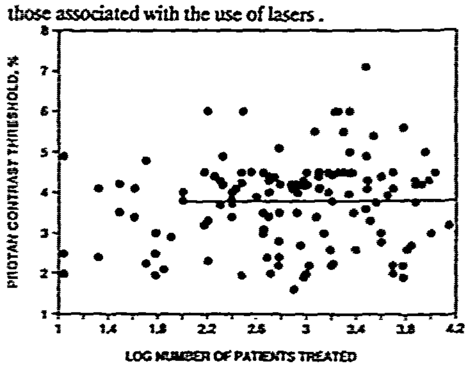

Figure 6 Relationship between the number of patients treated and protan threshold. The line is calculated from the relationship Threshold = 3.98 + 0.025 x log (patient number), and includes only results of surgeons who have treated more than 100 patients with lasers. The value of the correlation coefficient = 0.003 and the slope of the regression equation is not significantly different to zero.

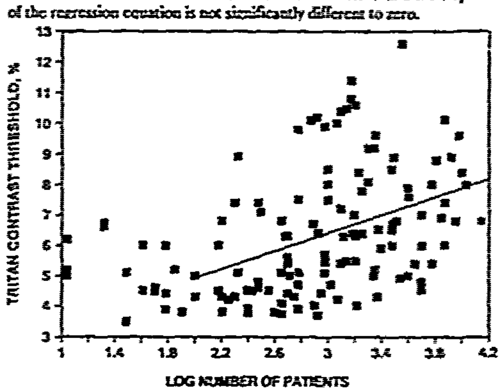

Figure 7 Relationship between the number of patients treated and tritan threshold. The line is calculated from the relationship Threshold = 2.02 + 1.46log (patient number), with results from surgeons who have treated more than 100 patients with lasers. The value of the correlation coefficient = 0.37 and the slope of the regression equation is significantly different to zero: the standard deviation of the slope is 4.5 times the value of the slope.

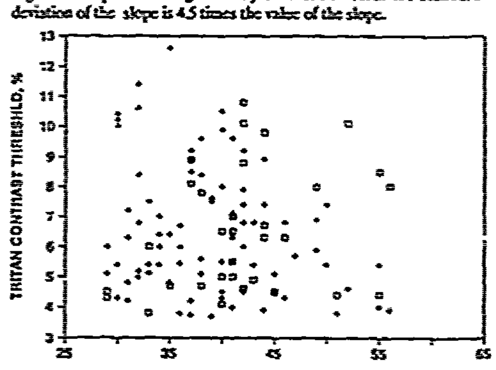

Figure 8:Relationship of tritan threshold to professional activity. Some of the highest thresholds are seen in younger surgeons, who operate intensively, but are not heavy users of lasers. Open squares, subjects who use lasers but do not operate: Crosses, subjects who both use lasers and operate.

DISCUSSION.

This survey confirms on a relatively large scale the previous reports of a deterioration in colour discrimination in ophthalmologists who use lasers. The changes are most obvious for colours lying along a tritan colour confusion axis. This cannot be explained as a result of age, since no such change can be seen in ophthalmologists who do not use lasers or operating microscopes. It is extremely unlikely that this correlation is adventitious because there is a significant relationship between threshold elevation and laser usage. Indeed it appears that eye surgeons at the outset of their careers may have better colour vision than their colleagues who largely limit themselves to a non- surgical practice. There is some evidence that red- green loss is also produced. This would be expected, for Argon blue light, wavelength 488 nm, is strongly absorbed in long- and medium-wavelength cones (peak absorption 565 and 550 nm respectively). The survey shows for the first time that there is a minor contribution from operating microscopes to the elevation in threshold, and 30 hours operating is equivalent to one pan-retinal photocoagulation. The regression equations predict that by the time between 1000 and 10000 patients have been treated, tritan thresholds will be abnormal by commonly accepted statistical standards. Given current average workloads this is in fair agreement with previous work on a small group which found the threshold of statistical abnormality to be crossed after 7 years[3]. There is a large scatter in the results, some of which is due to difficulties in the estimation of the number of patients treated, and part possibly due to differences in the equipment used, and the manner in which it is used. However, there seems to be an important " missing factor" for some ophthalmologists can apparently use lasers without any change while others are more severe affected. Further work is required to identify this factor. The degree of threshold elevation is comparable to that caused in several acquired conditions. Thus, although the threshold elevations seen here are below the limit of discrimination of the 100 hue test, they indicate that light is causing an undesirable level of disturbance to retinal function and we have no evidence that this change is reversible. Although surgeons employ bright lights, the intensity of naturally occurring and artificial luminous radiation is so great that some people who work in the open air must receive total retinal fluxes which are higher than for the busiest surgeon. It therefore seems prudent to discover if the findings reported in this paper are part of a larger picture of changes caused by light on the eye, and if such changes are related to any increase in pathological changes associated with age.

Acknowledgements: We thank: our colleagues in the Berufsverband der deutschen Augenarzte, and especially Prof. V-P Gabel, for their assistance: Messrs Rodenstock and Humphrey for the loan of equipment. The expenses of the investigation were defrayed in part by Zeiss /Oberkochen and Koherent/ Rodermark. GBA acknowledges support from the Wellcome Trust and the Wolfson Foundation.

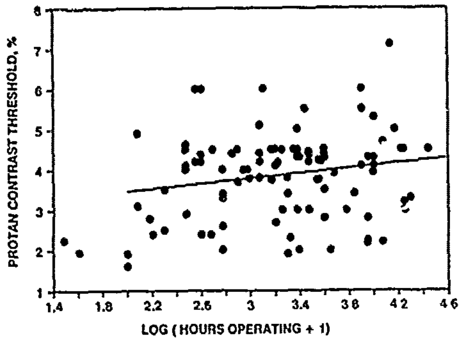

Figure 9:Relationship between protan threshold and number of operations performed. The regression line is calculated for those who have treated >100 patients. Threshold = 2.91 + .292 (log hours operating). r = 0.167. The slope ofthe regression equation is 1.7 times the standard error of the slope.

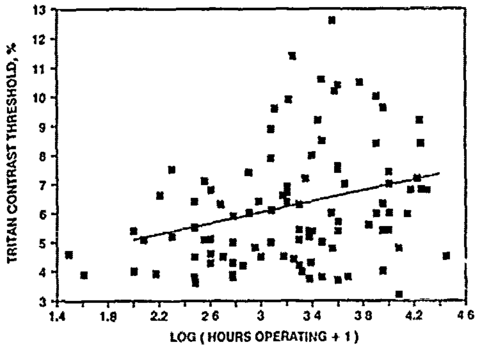

Figure 10.Relationship between tritan threshold and number of operations performed The regression line is calculated for those who have treated > 100 patients Threshold = 3.28 + .9175 (log hours operating). r = 0.279. The slope of the regression equation is 2.85 times the standard error of the slope.

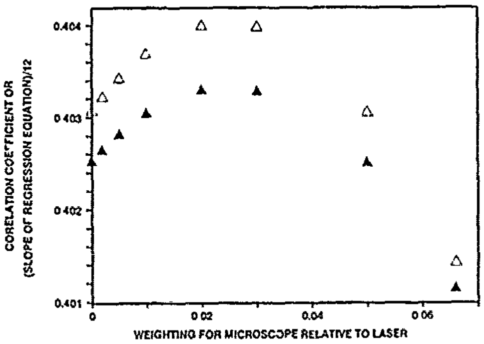

Figure 11: Relationship of threshold to various definitions of " total exposure". The hours spent operating were weighted, and added to the number of patients treated with Argon lasers. The abscissa indicates the weighting, a value of 0.1 indicating that 10 hours in theatre was equivalent to one retinal pan-photocoagulation. The resulting values were subject to regression analysis, and the ordinate shows variations in 2 measures, the correlation coefficient (closed triangles), and the variability of the slope as a fraction of the mean slope of the regression equation(open triangles). It is evident that an optimum weighting factor can be found, and thus the two activities are synergistic.

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MEDICAL MANAGEMENT OF COMBAT LASER EYE INJURIES

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ABSTRACT

The rapid growth of laser science and engineering has resulted in an increased use of lasers by the military. It is likely that in future engagements lasers will be used directly against our forces, and their effects on the health and mission performance of our aircrews are of particular concern. Since the optics of the eye can increase the retinal irradiance by a factor of 100,000 times over that which is incident at the cornea, the retina is especially vulnerable. Laser range finders and target designators are used in military operations, and energy inputs from these and other potential laser sources are sufficient to produce significant eye injury at distances of 1 km or more. Glare and flashblindness, which are temporary visual effects caused by visible lasers, are present for laser energies considerably below the damage threshold and can, therefore, interfere with mission performance at a considerably longer range. Aircrews partially protected by windscreens and canopies are still at risk from near infrared and visible lasers, while other personnel, such as air base ground defense forces, are additionally at risk from ultraviolet and far infrared lasers. Patients' symptoms from laser exposure will vary depending upon the power and wavelength of the laser, the structure of the eye affected, how close the exposure was to the visual axis, and the extent of the temporary or permanent effects on visual structures. Since most medical personnel in the field have never previously dealt with a patient who has had a laser exposure, a report which provides background information on lasers and guidance on handling these patients has been written.

MEDICAL MANAGEMENT OF COMBAT LASER EYE INJURIES

INTRODUCTION

A laser (light amplification by stimulated emission of radiation) is a device that emits an intense narrow beam of light at discrete wavelengths which range from the near-ultraviolet (invisible to the eye) through the color spectrum (visible) and into the far-infrared spectrum (also invisible). The rapid growth of laser science and engineering has resulted in the increased use of lasers by the military. Currently, laser range-finders and target designators are used in military operations by ground personnel, tanks, aircraft, ships, and anti-aircraft batteries. They are also used to simulate "live fire" in force exercises, where accidental injury to the eye may occur. It is likely that in future engagements lasers will be used directly against our forces. Thus, their effects on the health and mission performance of our aircrews will be of particular concern. Laser energy outputs are sufficient to produce significant eye injury even at distances of a kilometer or more. Currently, aircrews partially protected by windscreens and canopies are still at risk from near-infrared and visible lasers, while other personnel, such as air base ground defense forces, are additionally at risk from ultraviolet and far-infrared lasers. The injury effects of laser exposure, as well as the diagnosis, treatment, return to duty, and evacuation of injured personnel, will be addressed in this report.

PRINCIPLES OF LASER ENERGY

A laser produces a narrow, highly collimated beam of coherent (in phase) light which travels at 300,000 km per second, the speed of light. As distance from the laser source increases, the narrow beam will gradually diverge to a larger diameter. This beam can vary in wavelength throughout the electromagnetic spectrum (Fig. 1) and can be visible or invisible. Typically, laser wavelengths (often measured in nanometers - nm) are grouped into four major categories: ultraviolet (UV), 200-380 nm; visible, 380-760 nm; near-infrared (near-IR), 760-1400 nm; far-infrared (far-IR), 1400-10^6 nm.

Lasers emit energy continuously (continuous wave - CW) or in short bursts (pulsed). The number of pulses that a laser emits within a given duration is the pulse repetition frequency (PRF). Confusion can result because CW lasers can appear to be pulsed, if their beam is "chopped," and pulsed lasers can appear to be CW lasers, if their PRF is too high for the eye to perceive the separate pulses (greater than 60 to 90 Hz). In addition, certain pulsed lasers can emit all of their energy compressed into time periods as brief as billionths of a second (nanoseconds - ns) or less. Some lasers, such as argon or krypton, can emit several discrete wavelengths simultaneously, although frequently the laser is adjusted to emit one wavelength at a time.

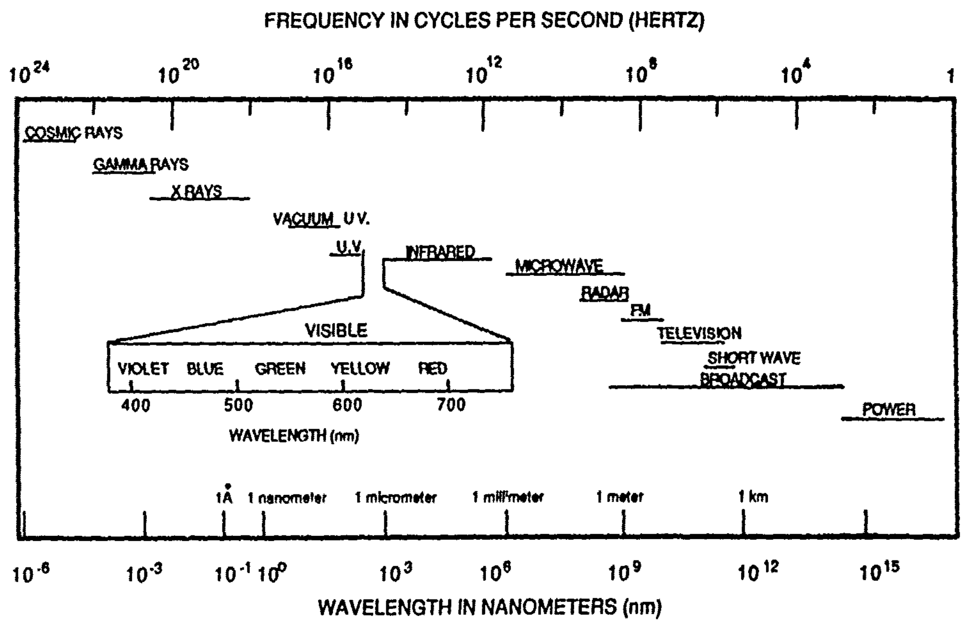

Figure 1. The radiant energy (electromagnetic) spectrum. (Adapted from McKinley, 1947)

The radiant power output of a laser at a given instant can be stated in watts, as with any light source. However, while the radiant output of CW lasers is usually given in watts, that of pulsed lasers is usually given in joules per pulse. A watt unit (W) is equal to an energy of one joule (J) per second, where a joule is defined as the energy required to raise the temperature of 1 cc of water by 0.239°C. A laser, unlike an ordinary incandescent light source, has a very small beam divergence and, thus, can direct most of its radiant power, over very small areas even at great distances. A measure of this radiant power, at a position in space, is called irradiance and has the units of watts per unit area (e.g., W/cm^2), while a measure of radiant energy, at a position in space, is called the radiant exposure and has the units of joules per unit area (e.g., J/cm^2). The radiant exposure of a laser is equal to its irradiance multiplied by the duration of time (in seconds) that irradiance is present at the position in question.

Laser light is gathered and focused by the eye across a 2-7 mm pupil to a retinal image about 5-30 microns in diameter. This focusing can increase the retinal irradiance by a factor of 100,000 over that which is incident at the cornea. A relatively low-output laser can produce serious eye injury simply because the eye focuses the beam and, thus, increases the retinal irradiance. The use of light-gathering and magnifying optical instruments, such as binoculars, and other optical sighting devices increases the danger from exposures because they collect more of the laser light and further increase the ocular irradiance.

BIOLOGICAL EFFECTS

Absorption of Light

The microscopic anatomy and the presence of pigments or chromophores in ocular tissues determine whether the tissue in question will absorb or transmit light.

1. Ultraviolet. Laser radiation in this spectrum (below 380 nm) is primarily absorbed in the anterior segment of the eye by the cornea and lens, as well as by the skin. Some near ultraviolet light (315-340 nm) will, however, reach the retina.

2. Visible. Laser radiation in this spectrum (380-760 nm) is absorbed primarily within the retina by the photoreceptors, pigment epithelium, and choroid, as well as by the skin. The longer wavelengths (red) are absorbed more deeply in the retinal/choroidal tissue than the shorter wavelengths (blue).

3. Infrared. Absorption of laser energy in this spectrum (above 760 nm) occurs in two areas of the eye, as well as the skin. Laser energy in the near-infrared spectrum (<1400 nm) is absorbed by the retina and choroid, whereas laser energy closer to the far end of the infrared spectrum (1400-10^6 nm) is absorbed by the cornea. A transition zone exists, from

1200 to 1400 nm, where retina, cornea, and lens are all at risk.

Damage Mechanisms

The amount of damage is, in general, proportional to the amount of laser energy the tissue absorbs and will be dependent upon the wavelength of the laser light, exposure duration, pulse width, repetition rate, and irradiance. There are three primary mechanisms of laser damage: actinic; thermal; and mechanical. Actinic insults generate photochemical processes and are more prevalent with UV and shorter visible wavelengths. Examples include UV corneal burns and sunburns of the skin. The injury mechanism of most low-power visible and IR continuous wave lasers is one of thermal photocoagulation, i.e., superficial and deep corneal burns and retinal burns. High-power CW and pulsed lasers produce both thermal burns and mechanical tissue disruption.

Description of Potential Damage

Cornea

The effect of ultraviolet radiation on the cornea is to produce epithelial injury, a condition that can be painful and visually handicapping. Minimal corneal lesions should heal within a few days, but meanwhile they could produce a decrement in visual performance.

Far-infrared radiation is also mainly absorbed by the cornea, producing immediate burns at all corneal layers. An infrared laser can produce a lesion which results in permanent scarring of the cornea. If the energy is sufficiently high, the cornea can be perforated; this perforation may lead to loss of the eye.

Retina and Choroid

The neurosensory retina is transparent to most wavelengths of visible light. However, laser energy in the visible range can produce inner retinal damage, although this is mainly secondary to the much greater absorption and destruction that takes place in the deeper and more pigmented tissue, the retinal pigment epithelium.

When the retinal pigment epithelium absorbs sufficient laser light energy, local thermal coagulation of adjacent photoreceptors and other structures of the retina also occurs. The surrounding retina will also be affected by edema. These processes result in a scotoma (blind spot) which varies in size depending upon the extent of the retinal damage. Vision may not be disturbed significantly by small retinal burns away from the fovea.

Visible and near-infrared lasers of sufficient power can produce hemorrhage in the choroid, a very vascular tissue, and disruption of the overlying retina. The visual loss from this hemorrhage may be quite severe. The blood may also move into the vitreous of the eye through the disrupted retina, where it may obstruct the passage of light through the ocular media. If extensive or centrally located, such hemorrhages can produce a significant loss of vision.

Skin Damage

The threshold for skin burns is similar to that of the cornea for ultraviolet and far-infrared wavelengths. For visible and near-infrared wavelengths, the skin's threshold is much higher than that for the retina, since the concentrating power of the eye is not a factor.

LASER EFFECTS ON VISION

Glare

Visible laser light can interfere with vision even at low energies which do not produce eye damage. Exposure to CW or rapidly pulsed, visible laser light can produce a glare, such as that produced by the sun, searchlights, or headlights.

Flashblindness and Afterimage

Visible laser light can also produce a lingering, yet temporary, visual loss associated with spatially localized aftereffects, similar to that produced by flashbulbs. Like glare, these aftereffects can occur at exposure levels which do not cause eye damage. One aftereffect, known as "flashblindness," is the inability to detect or resolve a visual target following exposure to a bright light.

The other aftereffect, often confused with flashblindness, is "afterimage." Afterimages are the perception of light, dark, or colored spots after exposure to a bright light. Small afterimages, through which one can see, may persist for minutes, hours, or days. Afterimages are very dynamic and can change in color ("flight of color"), size, and intensity depending upon the background being viewed. It is difficult to correlate the colors of afterimages with specific laser wavelengths. Afterimages are often annoying and distracting but are unlikely to cause a visual decrement.

Visual Loss from Damage

The permanent damage caused by UV, visible, and IR lasers can cause variable degradations in vision, proportionate to the degree of damage. Corneal damage may significantly degrade vision due to increased light scatter from opacities or due to gross rupture. In addition, iritis (intraocular inflammation), seen in association with corneal injuries, may cause photophobia, pain, and miosis (small pupil).

In the case of retinal damage, the severity of visual loss will depend upon the proximity and extent of the damage to the fovea. A graphic illustration of the potential Snellen visual acuities of the human retina, for high-contrast targets, is presented in Figure 2. It shows that the best visual acuity occurs in the foveola/fovea, and that the acuity falls off sharply when moving toward the peripheral retina.

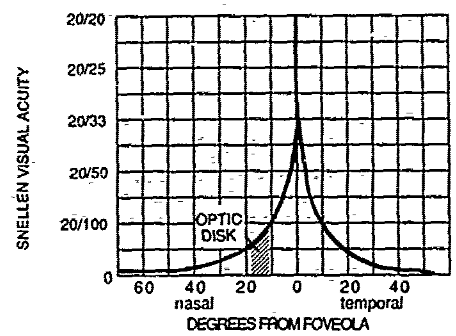

Figure 2. Acuity as a function of distance from the foveola. Acuity is greatest at the foveola and falls off sharply in the peripheral retina. The fall-off is relative to the maximal foveal acuity but has considerable individual variability. For illustrative purposes, this figure assumes that maximum visual acuity is 20/20 and relates the expected fall-off in vision to that maximum. (Adapted from Chapinis, 1949; data from Wertheim, 1894).

Functionally significant loss of vision usually occurs only if the burn directly affects the fovea. The expected minimum burn size (30-100 microns) for a low-power exposure to the fovea will have variable effects on visual acuity depending on location, with either no effect or a reduction in vision to approximately 20/40 for high-contrast targets. On the other hand, a direct laser burn to the foveola would definitely alter vision. If the retinal damage includes hemorrhages, the visual loss may be more profound, as the blood may block the passage of light to uninjured portions of the retina.

Central visual field defects caused by damage to the posterior pole will be noticeable and may be distracting or disabling, depending upon whether the foveola and, thus, visual acuity are affected. These central defects can be detected and characterized quite accurately with a simple test--the Amsler Grid.

A laser's light energy is likely to affect both eyes, unless one is occluded or otherwise protected, because the laser beam's diameter, at operationally significant distances, will be wider than the head.

SYMPTOMS

Symptoms will vary depending upon the location and severity of injury. Patients may give a history of experiencing glare, flashblindness, decreased vision, pain, or any combination. When seen by medical personnel, they may continue to complain of afterimages, blurred vision, photophobia, pain, or profound loss of vision. Obvious lesions, such as skin and corneal burns, and/or retinal burns and retinal hemorrhages make the diagnosis more certain, especially when accompanied by a history of seeing bright, colored lights.

EXAMINATION

History

The information provided in previous sections, along with appropriate intelligence questions, should all be used when questioning aircrews.

Routine Procedures

External Examination

The periocular tissue (lids and conjunctiva) and anterior segment (cornea, anterior chamber, and iris) of the eyes are evaluated on external examination. Laser injuries to the cornea will usually be limited to the area of the cornea within the palpebral fissure. Redness of the conjunctiva suggests ocular inflammation, possibly secondary to injury, that may be external or internal. A small pupil in the inflamed eye suggests, but does not confirm, the diagnosis of intraocular inflammation (iritis). The anterior chamber should be examined for blood.

Snellen Acuity

A "standard" eye chart (for distance or near) is used to measure visual resolution in each eye. The 20/20 characters on the chart have a letter height which projects an angle of 5 minutes of arc on the retina with 1 minute of arc features which, it is assumed, must be seen to correctly read the letters. This procedure tests foveal vision.

Confrontation Visual Fields

Finger-counting confrontation visual fields can be accomplished by the examiner facing the patient (at 1 m) and each closing the opposing eye. The examiner then extends his hands to the sides where he can see them with his open eye. He then flashes different numbers of fingers in each quadrant and elicits the patient's response. The same procedure is accomplished on the opposite eye. This procedure may help to identify gross peripheral visual field defects such as might be caused by a large hemorrhage, if the patient is unable to see the fingers of the examiner.

Amsler Grid

The Amsler Grid is a graph paper which, when held 30 cm (12 in) from the eye and viewed monocularly by the patient, can be used to plot areas of retinal injury or vitreous hemorrhage in the posterior pole (central 20 degrees). The Amsler Grid is sufficiently sensitive that it can detect lesions as small as 50 microns. Each eye should be tested separately. Figure 3 is a superimposition of an Amsler Grid on a drawing of the posterior pole to delineate the approximate area of the posterior pole tested by the Amsler Grid. The patient will report seeing visual distortion of the lines or a scotoma corresponding to the area of the posterior pole injured. The perceived visual field is upside-down and backwards to the corresponding retina, i.e., superotemporal retinal defects will be "seen" by the patient in his inferonasal field. The foveola corresponds to the central point of the visual field. Abnormalities in testing may indicate old stable conditions or new retinal/vitreal pathology. Bilateral abnormalities in the same areas of the visual field support the diagnosis of a laser eye injury. Figure 4 demonstrates laser scotomas due to bilateral, but unequal, foveal damage from a ruby range finder.

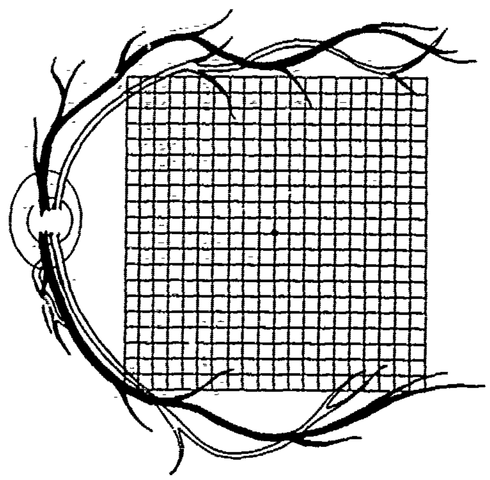

Figure 3. Area of the posterior pole tested by the Amsler Grid. (Adapted from Keeler (Hamblin) Lit., Amsler Charts Report).

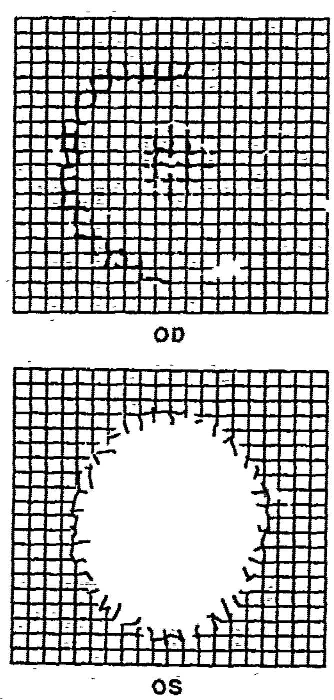

Figure 4. Amsler Grid abnormalities corresponding to foveal damage in both eyes. (Adapted from Lang et al., 1985).

Stereopsis

An evaluation of stereopsis can be conducted by using the VTA-DP test or the AO vectograph (distance measurements), or the Verhoeff apparatus or Randot Titmus (near measurements). The results are a good estimate of binocular visual function, as well as a test of foveal vision, as each eye must usually be at least 20/25 for an individual to pass.

Ophthalmoscopy

Using the direct ophthalmoscope, the examiner should be able to obtain a clear and undistorted view of the posterior pole in undamaged or mildly damaged eyes. Poor visualization of the posterior pole can result from corneal or lens opacities or a vitreal hemorrhage. Pharmacologic dilation may be used to facilitate this examination.

Special Tests

Fluorescein Staining

Fluorescein staining of the cornea will be helpful in detecting corneal epithelial defects in patients complaining of an ocular foreign-body or "scratchy" sensation.

Color Vision

Pseudoisochromatic plates are a series of color vision test plates in which colored dots are arranged in the shape of a number or letter. This test measures a function of the cone photoreceptors which are most numerous in the fovea centralis. If available, it may help in identifying a foveal injury. When used, it should be accomplished in each eye separately.

Tests for Malingering

The general types of malingerers include: individuals who deliberately feign a nonexistent visual loss; individuals who pretend that a condition is worse than it really is. Oddly, some individuals pretend that a disability does not exist. The reason malingerers feign disability is for secondary gain; they avoid a dangerous assignment or obtain a disability retirement.

In testing for total blindness (if monocular, you should cover the "good" eye), several simple objective tests can be done to demonstrate some vision:

1. Normal pupillary reflexes demonstrate the integrity of the lower visual pathways.

2. The Menace Reflex (quick avoiding blink)

3. The individual's ability to follow you rapidly through a crowded and disorderly room

4. Proprioception tests

5. Make faces at them.

6. The optokinetic nystagmus test (drum or tape) can rarely be suppressed.

7. If a mirror (at least 36 X 67 cm) is placed before the "blind" eye(s) and rocked, malingerers can often be "found out" because their seeing eye(s) follows the image in the mirror.

If you must demonstrate a specific level of vision, other more sophisticated tests may be used:

8. Stereoscopic tests (VTA-DP, Verhoeff, Randot Titmus, A-O Vectograph slide), if normal, suggest that the vision O.U. most probably is at least 20/25.

9. Surreptitiously blocking or fogging with "plus" lenses the vision in the "good" eye may enable you to demonstrate good vision in the "bad" eye.

10. Visual tests exist that require good vision in both eyes to read all the letters on the line, such as polarizing lenses with the Project-O-Chart slide and red/green lenses with the duochrome slide.

11. A 4-diopter or 6-diopter base-out prism, when placed quickly in front of the viewing "bad" eye, will cause a refixation shift and, thus, demonstrate that the eye was really fixating on the object of regard.

PHYSICAL FINDINGS

No clinical findings may be apparent, if only subjective symptoms (glare, flashblindness, or afterimages) have occurred as the result of a non-damaging exposure, or if there is retinal damage or hemorrhage outside the fine vision area of the posterior pole. The latter may be asymptomatic and not seen with the direct ophthalmoscope. Malingerers will generally have either no objective findings, or symptoms out of proportion to objective findings.

Clinical findings due to damage may be variable and include the following: isolated, rows, or groups of retinal burns; retinal/vitreal hemorrhages; and superficial or deep burns of the skin and cornea.

TREATMENT

Corneal Injuries

The treatment for corneal burns is the same as for burns of other etiologies, namely, the use of antibiotic coverage and eye dressings. The principles regarding [illegible]s, smoke inhalation, and airway maintenance must be followed. Patch only the eye with the injured cornea. Any associated iritis and its attendant pain can be treated with pupillary dilation using cyclogel 1%, one drop in the affected eye(s) every 8 to 12 hours. If the eye has been ruptured, the likelihood of saving it is low; do not use regular eye patches for such injuries, as these put pressure on the eye. Rather, the eye should be protected by a metal eye (Foxx) shield from any external pressure. Do not put any eye drops or ointments on a ruptured eye. The patient should be kept physically quiet in a supine position. In addition, the patient should be started on intravenous antibiotics, if possible. Priority of evacuation depends on the severity of injury and the likelihood of saving the eye. Pain medication may be required for patient comfort. Topical anesthetics should never be given to the patient, but they may be used by the physician to aid in the examination and treatment of nonruptured globes.

Retinal Injuries

At present, the treatment for laser injuries to the retina/choroid is not well-defined. Ocular and oral corticosteroids have not been proven effective for the treatment of retinal burns or hemorrhages. The use of eye patches for retinal damage is discouraged. Patching deprives the patient of his residual vision which may be quite good. It also has the effect of magnifying the visual impairment to the aircrew member and increasing his dependence on others. Personnel with vitreal hemorrhages should be maintained at bed rest with their heads positioned so that the blood settles away from the visual axis, particularly for the first few days. Delayed or tertiary treatment of vitreous hemorrhage consists of vitrectomy and associated procedures, but only for those eyes that do not have adequate spontaneous absorption of the blood. Patients with retinal damage currently have a low evacuation priority.

RETURN-TO-DUTY CRITERIA

An assessment of visual function and other findings, such as pain, should be made to determine how effective each individual will be to his unit. Personnel with best corrected visual acuities of at least 20/40 in the better eye and no worse than 20/400 in the other are returnable to duty. The specific duty they perform will be determined by the unit and the medical officer.

Aviators whose vision has been affected by a laser may remain at the front, but whether or not they perform aviation duties will be determined by the degree of vision loss, the extent of central visual field loss, whether the condition(s) is bilateral, the duties they are required to perform in the air, and the intensity of the engagement. Aviators with either large contained retinal or vitreous hemorrhages should not fly, as the blood may shift and occlude the visual axis. For the elective return of pilots to flight duty, the following short chart can serve as a general guide:

Best Visual Acuity		Amsler Grid	Stereopsis	Mission
Better eye	Worse eye			
20/20	20/30	Abnl one eye	Normal	All missions
20/25	20/30	Abnl O.U.	Normal	Air to ground or transport
20/30	20/40	Abnl O.U.	Abnormal	Emergency evacuation of aircraft in daylight

Other combinations of visual acuities are possible. The flight surgeon must use his best judgment, understanding the flying demands, in returning individuals with eye damage to flying duties. Aviators with 20/40 vision in their better eye should probably not be returned to flying duties. Bilateral foveal injuries, in spite of reasonable visual acuity, can cause a loss of confidence in a pilot with previously excellent vision.

EVACUATION CRITERIA

Personnel with best corrected vision worse than 20/40 in the better eye can be removed from duty and considered for evacuation. The capability of medical evacuation and the intensity of the engagement will determine whether these casualties will be evacuated or remain. Remember, soon after the injury, the vision may be poor, but it may improve over several days.

PSYCHOLOGICAL IMPACT

The use of laser weapons has the potential for having a very significant psychological impact on aircrew. Much of this impact can be alleviated by proper and well-directed education efforts. Some laser effects are only temporary and noninjurious. Acute visual loss due to laser injury may improve with time, and injured personnel should be given that hope. In addition, they should be reassured that it is unlikely that they will lose all vision and be "blind." The chief source of expert knowledge and education for commanders and their aircrew members will be medical personnel, particularly flight surgeons, ophthalmologists, and optometrists. The flight surgeon should actively participate in education sessions designed to teach the aircrews about lasers, their effects, and methods of self-protection.

A laser attack has the potential for occurring as a total surprise. Steps must be taken before engagement to alleviate fears of "death ray" lasers and helplessness in the air or on the battlefield due to loss of vision. Use of protective goggles and visors must be emphasized, and aircrews should be reassured that the use of appropriate devices will protect their eyes.

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REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-CP-492	ISBN 92-835-0616-2	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title OCULAR HAZARDS IN FLIGHT AND REMEDIAL MEASURES

7. Presented at the Aerospace Medical Panel Symposium held in London, United Kingdom, 22nd—26th October 1990.

8. Author(s)/Editor(s)	9. Date
Various	May 1991

10. Author's/Editor's Address	11. Pages
Various	126

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the back covers of all AGARD publications.

13. Keywords/Descriptors

Lasers	Filters
Solar radiation	Visual performance
Flashblindness	Contact lenses
Glare	Refractive surgery
Dazzle	Ophthalmology
Visors	

14. Abstract

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In unclassified sessions, 11 ophthalmological papers were presented. Those covered the operational use of contact lenses by military aircrew, cataract surgery and intra-ocular lenses, the correction of refractive errors by radial keratotomy, impairment of colour vision in ophthalmologists using argon lasers, and the medical management of combat laser eye injuries.

AGARD Conference Proceedings No.492
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OCULAR HAZARDS IN FLIGHT AND REMEDIAL MEASURES
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publié par le National Technical Information Service
Springfield
Virginia 22161
Etats-Unis
(accessible également en mode interactif dans la base de données bibliographiques en ligne du NTIS, et sur CD-ROM)

Imprimé par Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ

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Springfield
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(also available online in the NTIS Bibliographic
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ISBN 92-835-0616-2