Occupational Ocular UV Exposure in Civilian Aircrew

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INTRODUCTION: Ultraviolet radiation (UVR) increases with altitude; however, there are a number of other factors which may influence ocular exposure during flight. The aim of this study was to assess ocular UVR exposure of pilots in airline and off-shore helicopter operations on different aircraft types and to compare with exposure in a typical office environment.

METHOD: In-flight data were captured on equipment including a CCD array spectroradiometer on five return sector European airline flights and one transatlantic flight from London Gatwick in addition to four helicopter flights from Aberdeen Dyce airport. Further data were collected in an office environment from three workstations during summer and winter months.

RESULTS: A wide variation in ocular UVA dose was found during flights. The main factor influencing exposure was the UVR transmission of the windshield, which fell into two distinct profile types. In an aircraft with good UVA blocking properties, ocular exposure was found to be equivalent to office exposure and did not exceed international guideline limits regardless of external conditions or flight time. Most aircraft assessed had poor UVA blocking windshields which resulted in an ocular exposure to the unprotected eye in excess of international guideline limits (up to between 4.5 to 6.5 times greater during one flight). No significant UVB dose was found.

DISCUSSION: Pilots should be warned of the potential high UVA exposure during flight and advised on the use of sunglasses. A windshield labeling system would allow the pilot to tailor their eye protection practices to that particular aircraft.

KEYWORDS: pilots, eye, sunglasses, ultraviolet, irradiance.

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Pilots are exposed to large variations in the level of solar radiation during flight. Ultraviolet radiation (UVR) increases by 10–12% every 1000 m (3280 ft) in altitude.[3,28] This translates to a 170–290% increase in UVR between sea level and a cruise altitude of 35,000 ft (10,668 m). Factors influencing ocular exposure include the position of the solar disc in relation to the aircraft, reflection of radiation from surfaces below the aircraft such as snow or cloud top, filtering effect of the ozone layer, altitude, transmission properties of the cockpit windshield and pilot use of eye protection (such as sunglasses). Ocular UVR doses are likely to be increased where there are less atmospheric pollutants and where there is a lower solar elevation angle closer to the line of sight.

The eyes and skin are at most risk of excessive exposure to UVR.[27] More than 99% of UVR below 340 nm is absorbed by the cornea and lens. It is known that intense exposure to UVR of the cornea, which absorbs all UVR below 300 nm and 40% of UVR at 320 nm, can cause photokeratitis;[26] this has not been reported for flight crews as the UVR levels from the sun in the cockpit are not sufficiently intense to invoke this response.

A large body of evidence supports the proposition that long term exposure to UVR is a risk factor for cataracts.[9,10,19] UVR induced cataracts arise through oxidative stress causing increases in reactive oxygen species (chemically reactive molecules which can, in turn, cause damage to the lens DNA and cross-linking of proteins).[4] Cataract development is multifactorial; age is a strong risk factor although other reported risk factors include cigarette smoking, diabetes, nutrition, obesity, genetic factors, steroids, and alcohol.[1] However, there is a higher

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risk of cortical cataract with UVR exposure consistent through different study designs, different populations and varying levels of other known risk factors.[20]

The presence of cataract, even in early stages, can affect visual performance, particularly in low light conditions. It can reduce visual acuity and contrast sensitivity[2] and cause increased symptoms of glare through intraocular light scatter.[4] Although there is no strong evidence of an increased prevalence of cataracts in airline pilots,[5] no study questioned pilots on their use of optical correction, including sunglasses.

In order to ensure protection from ocular damage through nonionizing radiation, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has produced guidance on limits for radiation between 180 to 400 nm.[13] Effective radiant exposure (spectrally weighted with UVR hazard function) to the unprotected eye should not exceed 30 $J \cdot m^{-2}$, and for wavelengths between 315 to 400 nm the UV radiant exposure should not exceed 1×10^4 $J \cdot m^{-2}$ within an 8-h period. ICNIRP state that the exposure limits should be considered an absolute for direct exposure of the eye.[13]

Previous research[21] measuring the transmission of a small selection of aircraft windshields found a transmittance less than 1% from 280 to 320 nm (UVB) through both glass and plastic windshields. Transmittance varied between 0.41% and 53.5% from 320 to 380 nm (UVA) with plastic materials (such as found in general aviation aircraft) showing superior UVR blocking.

Diffey and Roscoe[11] measured UVR exposure on 12 flights including long and short haul using a polysulphone film badge worn by pilots on a wide variety of routes worldwide. The cumulative exposure to the film was measured; however, as the sensitivity of the film was "confined principally to wavelengths less than 320 nm" (which would have been effectively blocked by the aircraft windshield), results showed that all badges worn during flight had minimal exposure to UV radiation and no data were provided regarding ocular exposure to UVA.

The aim of the present research was to assess the occupational ocular UV dose of pilots onboard a series of flights to various destinations at different times of year. This is compared with a series of measurements conducted in office environments over a normal 8-h working shift. Based on these data, calculations of the likely annual pilot UVA ocular exposures are made. The spectral transmission properties of a series of aircraft windshields from current registered aircraft are also assessed.

METHODS

Equipment

Spectral irradiance and transmission measurements were carried out using an Ocean Optics HR4000 miniature CCD array spectroradiometer (Ocean Optics Inc, Dunedin, FL). Optical radiation was collected through a CC-3-UV cosine corrected diffuser (Ocean Optics Inc, Dunedin, FL) and transmitted via a metal sleeved QP600-2-UV/BX 2 meter fiber optic cable (Ocean Optics Inc, Dunedin, FL). The Spectroradiometer was connected to an ASUS R2E palmtop computer on which was installed Automated Spectrometer Acquisition System (ASAS) and Ocean Optics SpectraSuite software to facilitate data collection and storage. ASAS was used for data collection during flight and SpectraSuite software was used for transmittance measurements of aircraft windshields.

To allow concurrent dark measurements, an INLINE-TTL-S optical shutter (Ocean Optics Inc, Dunedin, FL) was connected directly to the HR4000 and controlled by ASAS software. Both shutter and palmtop were powered by an external battery allowing up to 8 h of continuous operation. There was no reliance on the use of aircraft electrical power. Detailed description of operation and measurement methods are previously described.[7] Additionally, two miniatureTR-74U*i* illuminance UV Recorders (T&D Corp, Japan) were used to record illuminance during flight.

Procedure

The HR4000 was calibrated using a 1 kW Tungsten Halogen calibration lamp (traceable to Physikalisch-Technische Bundensanstalt (PTB) reference standards) and for in-flight measurements using the solar spectrum and a scanning double-grating spectroradiometer D[3] 180 (Jobin Yvon, Longjumeau, France) as a reference instrument. Wavelength accuracy was assessed using a low pressure Hg Pen-Ray@ lamp and additionally before and after each deployment using the mercury peaks from a standard fluorescent tube light. The HR4000 was found to have good stability within the measurement uncertainties. The effect of spectroradiometer sensitivity with temperature was quantified.[22] Throughout all flights, the HR4000 unit was placed in a shaded location in the cockpit, away from any heat generation from the palmtop or batteries; this maintained the board temperature stability within the 22°C to 35°C optimum operating range. Both illuminance UV recorders were assessed and showed good correlation with each other and the spectroradiometer.[7] One unit was secured at a fixed position next to the input optics of the HR4000 and was programmed to capture illuminance data time-synchronized with spectral measurements.

The spectroradiometer and illuminance UV recorder diffusers were located close to the front aircraft windshield away from aircraft frame structure and were positioned such as not to cause distraction to the pilot. The second illuminance UV recorder was used by the researcher to take a series of manual readings during flight. The position of the input optics of the spectroradiometer relative to the pilot eye position was no greater than 70 cm from the pilot operating from that side of the aircraft. Measurement of the spectra at both locations showed minimal variation across the spectrum.

In-flight illuminance data were recorded manually every 10 min during spectral data collection at the pilot eye level facing forward over the instrument cowling to simulate the pilot looking straight ahead through the front windshield. A second reading was taken from the same position with the sensor angled downwards toward the primary flight instrument displays. The researcher's wristwatch and the palmtop were time synchronized.

Additional data were collected on push-back, taxi, takeoff, and landing times. The researcher also made observations from the jump seat of altitude, weather conditions, cloud cover, and the use by pilots of aircraft sun visors or blinds.

The spectroradiometer was also used to assess ocular UV exposure in an office environment of three workstations in the UK Civil Aviation Authority's Safety and Airspace Regulation Group building (Gatwick Airport, 51°09'N, 0°11'W). Workstation 1 had a ground floor location in a room with large windows across both south and west facing walls. The workstation was situated near the south facing window. Workstation 2 was located on the ground floor, facing south in an open plan office area nearer the center of the building and away from any external windows. Limited natural daylight was visible through the glass ceiling above the third floor of the nearby atrium. Both workstations were lit by ceiling fluorescent tube lighting. Workstation 3 was a clinical consulting room which contained no windows and had no access to daylight. Lighting was provided by ceiling fluorescent tube and tungsten spot lighting.

Measurements from each workstation were taken during February 2013 and July 2013 over an 8-h continuous period using the same settings as for all flight data. The room containing workstation 1 had horizontal blinds fitted and 2 d of data collection at this location were carried out in February 2013. The first day the blind slats were closed and the second day the blind slats were open but not raised. An additional day of data collection was carried out in July 2013 with the room blind slats open but not raised.

Spectral transmission of windshields were also measured on a series of airline aircraft parked at airport stands and measurements were taken from the following positions:

- Facing forward within 5 cm of right windshield
- Facing forward within 5 cm of left windshield
- Outside facing forward at the same fore/aft position with probe held out of open side window
- Facing forward within 5 cm of a deployed front right visor
- Facing forward within 5 cm of a deployed front left visor
- Facing toward right side window within 5 cm of inside surface
- Facing toward right side window with side blind deployed and within in 5 cm of surface
- Facing toward left side window within 5 cm of inside surface
- Facing toward left side window with side blind deployed and within 5 cm of surface.

Measurements were made on 6 November 2012 (London Heathrow 51°28'N, 0°27'W), 16 April 2013 (London Heathrow 51°28'N, 0°27'W), and 28 August 2013 (Exeter International 50°44'N, 3°25'W). On each occasion, weather conditions were dry with some scattered cloud cover present. Additionally, windshield transmission measurements were taken on 25 June 2013 (Brooklands Museum, Weybridge 51°21'N, 0°28'W) and on flights 5 and 6 during turnaround at Alicante and Rhodes, respectively, where conditions were sunny and cloud free.

Data Analysis

For each spectral measurement, the following were calculated: UVA irradiance, blue light weighted irradiance, and erythema weighted irradiance and illuminance. A flight summary was created for each flight incorporating data from both illuminance UV recorders and flight information. UVA dose throughout all sectors flown were calculated.

The ratio between the two illuminance UV recorders at each timed measurement was calculated. For calculation of ocular exposure, each pair of ratios (for both eyes ahead and down) was applied to time matched spectral data. Where illuminance UV recorder and spectral data were not exactly time matched, spectral data were calculated using the closest two readings and assumed a constant change over the 10-min interval. Irradiances in both positions, eyes ahead and eyes down, were calculated and an additional UV dose assessment was made incorporating dose received during turnaround at the destination airport based on the turnaround time and a mean of the last reading from the outbound sector and first for the inbound sector which were both recorded at the stand at the destination airport.

Using time and altitude data, ground and cruise altitude data were identified and compared for calculation of the mean increase in irradiance and illuminance at altitude. Here, readings taken during climb and descent were not used.

RESULTS

A summary of airline flights undertaken is shown in **Table I.** All flights were undertaken during daylight hours. Erythema weighted irradiance and UVB irradiance was insignificant on all flights. UVA irradiance in $W \cdot m^{-2}$ for each spectrum was calculated from 315 - 400 nm and a summary of UVA radiant dose in $J \cdot m^{-2}$ for each flight is shown in **Table II**.

The direction of visual attention changes during flight and is mainly a combination of 'eyes down' toward instruments and 'eyes ahead' looking through the front aircraft windshield. Therefore, 'down' and 'ahead' should be considered the minimum and maximum ocular exposures, respectively. For each flight of two sectors, a further UVA dose has been calculated to incorporate ocular exposure during turnaround to give a value of ocular UVA exposure over the pilot's working shift. These doses are compared with the ICNIRP Exposure Limits for 8 h accumulative radiant exposures.

During flight 5, the ICNIRP guideline limit was exceeded within 1 h after takeoff from London Gatwick assuming an 'eyes down' position or in less than 30 min after takeoff assuming an 'eyes ahead' position. This also assumes that the pilot had no ocular UV protection such as sunglasses. Where aircraft visors were deployed, it was noted that a relatively small area of the total front windshield was covered and that significant diffuse radiation was still present. When the aircraft visors were used, a higher difference between measurements at windshield and pilot eye position would result. The mean increase in UVA at altitude during airline flights was 2.4 times. The ocular UVA exposure on different flights varied widely. Flights 2 and 3 were

Table I. Summary of Airline Flights.

FLIGHT	DATE	DEPARTURE AIRPORT	DESTINATION AIRPORT	AIRCRAFT TYPE	MAX ALTITUDE (FLIGHT LEVEL)	DURATION EXCL. TAXI (min)	DURATION INCL. TURNAROUND (min)
1a	16 May 2012	London Gatwick 51°09'N, 0°11'W	Faro, Portugal 37°01'N, 7°58'W	A320	370	143	385
1b	16 May 2012	Faro, Portugal 37°01'N, 7°58'W	London Gatwick 51°09'N, 0°11'W	A320	360	147	
2a	22 May 2012	London Gatwick 51°09'N, 0°11'W	Barcelona, Spain 41°18'N, 2°05'E	A320	390	93	315
2b	22 May 2012	Barcelona, Spain 41°18'N, 2°05'E	London Gatwick 51°09'N, 0°11'W	A320	380	113	
3a	26 May 2012	London Gatwick 51°09'N, 0°11'W	Barcelona, Spain 41°18'N, 2°05'E	A320	330	98	294
3b	26 May 2012	Barcelona, Spain 41°18'N, 2°05'E	London Gatwick 51°09'N, 0°11'W	A320	380	106	
4	21 Nov 2012	London Gatwick 51°09'N, 0°11'W	Tobago 11°09'N, 60°50'W	A330	400	555	
5a	01 Mar 2013	London Gatwick 51°09'N, 0°11'W	Alicante, Spain 38°17'N, 0°34'W	A321	350	127	376
5b	01 Mar 2013	Alicante, Spain 38°17'N, 0°34'W	London Gatwick 51°09'N, 0°11'W	A321	340	131	
6a	21 Aug 2013	London Gatwick 51°09'N, 0°11'W	Rhodes, Greece 36°24'N, 28°05'E	B757	370	220	544
6b	21 Aug 2013	Rhodes, Greece 36°24'N, 28°05'E	London Gatwick 51°09'N, 0°11'W	B757	380	232	

conducted at near identical times of year and time of day. The destination was the same and the flight times were equivalent in all key respects. Weather conditions for both flights were similar and relatively cloud free. The aircraft type (Airbus A320) was the same on each flight; however, the two individual aircraft were different. The aircraft used for flight 2 was built in 2001 and had a total flight time of 37,526 h logged at 31/12/2012. The aircraft used for flight 3 was built in 1994 and had a total flight time of 69,461 h logged at 31/12/2012. The pilot flying the newer aircraft received over 11 times the UVA dose to that of the pilot flying the older aircraft. The large difference in UVR exposure was due to differences in the transmission characteristics of the two aircrafts' windshields; an example of a spectral irradiance at cruise altitude on each outbound flight is shown in **Fig. 1**.

The two spectra are similar from 420 – 700 nm; however, a large difference in the irradiance between 340 and 420 nm results in more than an order of magnitude difference in UV exposure. UVA dose is, therefore, highly dependent on the type of windshield installed. It is clear from the data that flights 3 (Barcelona) and 4 (Tobago) were undertaken in aircraft with good UVA attenuating windshield properties.

Table II. Summary of UVA Dose Relative to ICNIRP 10,000 $J \cdot m^{-2}$ Limit for Extended Viewing Both With and Without Destination Turnaround Time.

FLIGHT	UVA DOSE DURING FLIGHT: EYES AHEAD	UVA DOSE DURING FLIGHT: EYES DOWN	FLIGHT DURATION (min)	UVA DOSE INCLUDING TURNAROUND: EYES AHEAD	UVA DOSE INCLUDING TURNAROUND: EYES DOWN
1 Faro	2.34	1.18	290	3.04	1.53
2 Barcelona	1.70	1.03	206	1.96	1.22
3 Barcelona	0.15	0.08	204	0.16	0.09
4 Tobago	0.22	0.17	588	N/A	N/A
5 Alicante	3.82	2.67	301	3.94	2.77
6 Rhodes	6.24	4.21	479	6.56	4.55

Four return trip helicopter flights were undertaken from Aberdeen Dyce International airport to various offshore oil platforms. Flight times including turnaround ranged between 115 and 174 min and the cruising altitude on a particular sector ranged from 1100 to 3000 ft (335 to 914 m). A large difference in UVA dose was also seen within these flights; the UV dose compared with the ICNIRP Exposure Limit ranged from 0.02 to 0.10 onboard two flights on a Sikorsky 92a and from 1.03 to 2.85 on two flights on a Eurocopter AS332 Super Puma aircraft.

The reference manual for the Sikorsky 92a describes the aircraft as having a glass/acrylic plastic laminate windshield. It is likely that the addition of this plastic layer in the windshield construction offers better UVA attenuation as clear acrylic material can, with additives, be manufactured to block up to 98% of UV,[23] which would be responsible for the low UVA detected in this aircraft. Overall, a mean 1.9 times increase in UVA was found at altitude compared to ground level on helicopter flights.

Although helicopter flights were taken on consecutive days at similar times of day, weather conditions for flights onboard the AS332 aircraft were much sunnier and cloud free compared to the second day of measurements (onboard the S92a) which was more overcast and involved more flight time in or below cloud. The data from the two days of flights indicate the likely range of ocular UV exposure for the North Sea off shore helicopter pilots in early spring.

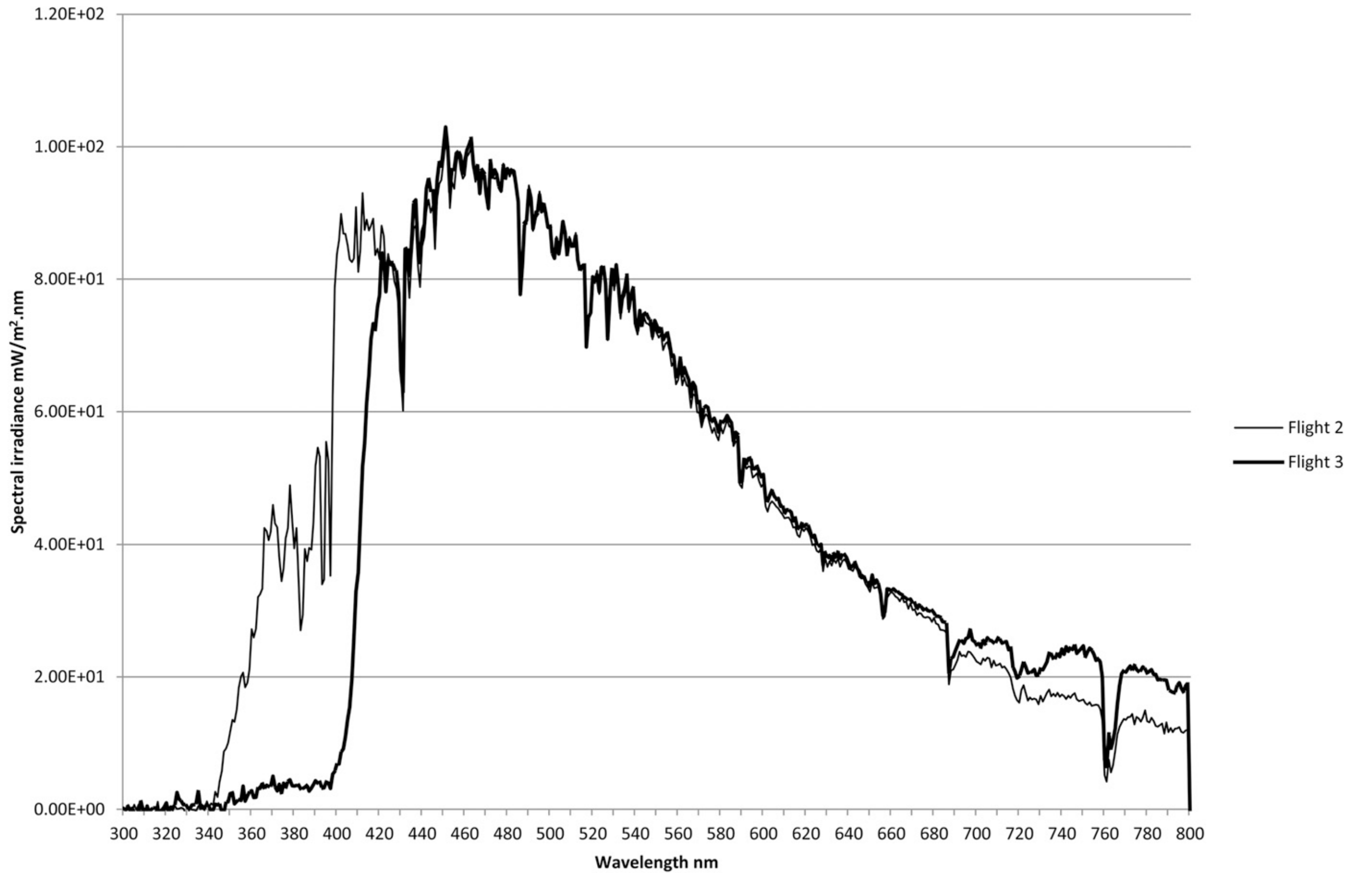

Fig. 1. Example of spectral irradiance measured during cruise on flights 2 and 3.

Erythema weighted irradiance was insignificant due to the UVB blocking of all windshields. For comparison, UVR dose rates of office workers and pilots for each flight are shown in **Table III**. The ocular UVA doses from all office workstations at both times of year fell within ICNIRP guidelines and varied between 0.19 (workstation 2 in winter) to 0.28 (workstation 3 in summer and winter).

Windshield spectral transmittance data were collected from 15 aircraft of various aircraft types including Boeing (B747, B757, B777), Airbus (A320, A321), Embraer (195) and Bombardier (Dash8). Outside measurements were not possible from the B747 as there were no opening side windows fitted on this aircraft.

For all windshields, it was possible to ascertain the point at which a UVA signal was detectable (**Table IV**). The Airbus A321 was also used for in-flight measurements on flight 5 and the Boeing B757 was used for flight 6. The windshields all fell into one of two distinct categories: those windshields with minimal transmission below 400 nm and those windshields with minimal transmission below 360 nm but where spectral transmittance increased from around 360 nm and which allowed significant transmittance by 400 nm. These are described as either good or poor UVA attenuators.

Estimation of Annual UVA Dose

UK professional pilots are limited to a maximum of 900 flying hours per annum.[8] Two airlines operators participating in the research were questioned regarding the likely number of hours logged per annum of a full time employed pilot and additionally the amount of time operating during daylight hours. There were a number of considerations in the estimation of annual daylight flying hours which included the type of flight operation (seasonal holiday destinations, city destinations, long haul or short haul), the size of the base from which the pilot operated, the number of waves aircraft operate from their base airport and the number of sectors flown by the pilot per working day.

Based on these considerations and data obtained from operators, it was estimated that a short haul pilot would expect to fly a minimum of 480 daylight hours per annum if operating from a smaller UK base and up to 780 daylight hours per annum from a larger UK base. The long haul pilot would fly approximately 420 daylight hours per annum and this could be less depending on pilot rotation and crew rest breaks on flights with three (or four) pilots present. The calculated annual occupational ocular UVA dose to the unprotected eye would be between 84,000 to 137,000 $J \cdot m^{-2}$ for the long haul pilot operating an aircraft with good UVA attenuating windshields and up to between 3.1×10^6 to 4.9×10^6 $J \cdot m^{-2}$ for the busy short haul pilot operating aircraft with poor UVA attenuating windshields.

DISCUSSION

Although visual inspection revealed no observable differences between the windshields installed on the aircraft flown, there

Table III. Summary of Ocular UVA Dose Rate in Jm^{-2} per hour for Each Flight and at Office Workstations.

FLIGHT	OCULAR UVA DOSE RATE ($J \cdot m^{-2} \cdot hr^{-1}$) EYES AHEAD	EYES DOWN
1 Faro	4842	2442
2 Barcelona	4966	3006
3 Barcelona	432	227
4 Tobago	221	173
5 Alicante	7606	5323
6 Rhodes	7816	5277
7 Heli flight 1	7390	4297
8 Heli flight 2	12,740	6471
9 Heli flight 3	370	228
10 Heli flight 4	114	74
WS 1 (winter BC)	279	
WS 1 (winter BO)	281	
WS 1 (summer BO)	269	
WS 2 (winter)	241	
WS 2 (summer)	264	
WS 3 (winter)	345	
WS 3 (summer)	347	

WS = worskstation; BC = blind slats closed; BO = blind slats open.

were large differences in UVA exposures measured on different aircraft. On board an aircraft with a good UV blocking windshield, the evidence suggests that ocular UVA radiant exposure will not exceed ICNIRP guidelines regardless of the flight time, position of sun or external conditions. Windshields from flights with a higher UVA radiant exposure showed an increase in transmittance from around 360 nm. All flights on board aircraft with poorer UVA blocking windshields have been shown to result in an ocular UVA exposure in excess of ICNIRP guidelines. This may occur where flight conditions may not feel excessively bright to the pilot. As pilots currently have no means to assess the UV blocking properties of a particular windshield and the level of UVB is insignificant to result in a suntan, they may inadvertently be subject to a significantly higher UVA dose without using appropriate eye protection.

Airline windshields are generally thick and constructed of multilaminate glass. A heating element layer is present and the windshield is constructed to withstand impact, high cyclical temperature loads and cabin pressurization. The windshield should transmit the majority of incident visible light, although a small percentage will be reflected at each laminate surface interface. Of the current registered aircraft used for ground transmission measurements ($N = 14$), 4 (29%) would be considered to have good UVA attenuating front windshields. The aircraft assessed ranged in age from a Boeing 777-300 registered in 2011 to a Boeing 757 registered in 1987. It is observed that the four oldest registered aircraft measured were three Boeing 747s (registered 1990, 1991, and 1993) and a Boeing 757 (1987). Of these aircraft, three had good UVA attenuating front windows. Additionally, the decommissioned Concorde built in 1972 showed better UVA attenuating properties than many of the newer aircraft.

Information gained from airline engineering departments revealed that there is no scheduled replacement of windshields. Although the fixings to secure the windshield in place are replaced, the windshield itself is inspected and replaced when damage such as cracks or de-lamination occurs. It was not possible to access any information on the windshield replacement history (if any) on the aircraft measured in this study. All aircraft measured showed similar UVA attenuating characteristics for left and right windshields and it could be argued that if windshields were replaced routinely, there could be a higher probability that the left and right front windshields would show different transmission properties if not replaced at the same time. It is not known why a difference in windshield transmission exists. It is speculated that there may be a higher financial implication of manufacturing a windshield with good UVA attenuating properties.

There was no correlation observed between the aircraft manufacturer or aircraft type and the UVA windshield attenuation. Indeed, aircraft of the same type showed different windshield attenuation. Based on the data, it is suggested that the prevalence of good UVA attenuating windshields on commercial passenger airplanes will decrease over time as all of the newest aircraft assessed had poor UVA attenuating windshields. As older fleets (such as the Boeing 747) are replaced with new aircraft types (such as the Boeing 787), a significant increase of accumulative pilot UVR exposure may result.

Pilots have independently reported an assumption that windshields provide adequate protection from UV. This assumption is based, at least in part, on the lack of skin tanning during flight and the thickness of the

Table IV. Summary of Aircraft Used for Ground Measurements Together with the Windshield UVA Attenuation.

AIRCRAFT TYPE	BUILT	AIRFRAME HOURS	DATE AS OF	UV ATTENUATION* R FRONT	L FRONT	R SIDE	L SIDE
B777-200	2000	48,780	31/12/2011	poor	poor	poor	poor
B747-400	1993	89,575	31/12/2012	good	good	good	no data
B777-200	1999	54,961	31/12/2011	poor	poor	no data	no data
A321-200	2004	23,440	31/12/2011	poor	poor	poor	good
B777-300	2011	919	31/12/2011	poor	poor	good	poor
B777-200	1998	66,296	31/12/2012	poor	poor	poor	poor
B777-200	1997	62,462	31/12/2011	poor	poor	good	good
B747-400	1991	90,272	31/12/2011	good	good	good	good
B777-200	1998	61,318	31/12/2011	poor	poor	poor	good
B747-400	1990	101,859	31/12/2011	good	good	good	good
A320-200	2007	10,703	31/12/2011	poor	poor	good	good
Concorde	1973	not available		good	good	poor	no data
Embraer 195	2008	8413	31/12/2012	poor	poor	good	good
Bombardier Dash8	2005	12,195	31/12/2011	good	good	good	good
B757-2T7	1987	91,829	31/12/2012	poor	poor	good	good

* Good UVA attenuation is where transmission is negligible below 400 nm. Poor UVA attenuation is where transmission increases from 360 nm.

windshield.[6] Therefore, information should be available to professional pilots to state that some UV radiation may pass through the front aircraft windshields. Although this would be the less energetic, 'near visible' UVA part of the electromagnetic spectrum which does not cause skin tanning, irradiance levels at altitude are sufficiently high that a significant ocular UVA dose may be received inside the cockpit. Sufficient UVA protection from a windshield should not be assumed.

Currently, the pilot has no means to assess the windshield attenuation of a particular aircraft. This should be addressed. An optimum solution would be to replace all poor UVA attenuating windshields with windshields of better UVA attenuation. However, this is unlikely to be considered a feasible option due to cost and the lack of evidence of acute health effects. Therefore, in the absence of this, it is recommended that windshields should be assessed and labeled so that every pilot using that aircraft has the opportunity to tailor their ocular protection strategies accordingly.

The use of a spectroradiometer by the pilot to assess each aircraft's windshield would be costly and impractical. Further research is required in order to develop cost-effective express diagnostic methods to guide pilots.

Pilots should also be informed that sunglasses or UV absorbing contact lenses will provide better control of UV reaching the eye than the use of aircraft visors which only attenuate radiation through a proportion of the windshield. Investigations into the transmission properties of pilots' eyewear have been carried out and we plan to report on this in due course. Eye healthcare professionals and aviation medicine specialists should be able to make appropriate recommendations for ocular UVR protection to pilot patients. This information would additionally raise awareness within the pilot population of the potential risk of long term UVA exposure to health. Exposure to UVR is an important risk factor for all types of cutaneous cancers[12,14,24] and repetitive exposures to suberythema UV is reported to have an cumulative effect which can produce early skin alterations indicative of skin damage,[16–18] premature photo-aging and wrinkling. Kligman and Gebre[15] report that UVA causes biochemical changes in mouse skin, and authors including Wang et al.[25] have linked UVA exposure to an increased risk of malignant melanoma induction.

No significant UVB was measured during any flight, which concurs with previous research.[11] However, this study has shown that the UV transmission of the windshield is the most important factor in determining the UVA dose during flight. On board an aircraft with a good UVA attenuating windshield, data show that the unprotected eye does not receive a UVA dose above recommended exposure limits even if of long duration and during bright sunlight conditions; however, this was not the case for the majority of the aircraft windshields assessed.

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