QUANTITATIVE EVALUATION OF THE PERSONAL ERYTHEMAL ULTRAVIOLET EXPOSURE IN A CAR

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Abstract

The erythemal ultraviolet (UV) exposures to the right hand, mid-arm, shoulder, chin, nose and left and right sides of the face have been evaluated in a car from the large family class and a car from the small car class. In the small car, the highest exposure site received 2.2 times more exposure than the highest exposure site in the larger car. In both cars, the highest erythemal exposures to the body sites are to the body region of the right shoulder, arm and hand. Over a six hour period, the erythemal exposure to the right shoulder of a person in the driver's seat of the small car was 3.1 mJ cm^{-2}.

Introduction

Exposure to harmful solar ultraviolet (UV) radiation is linked to the incidence of skin cancers, irreversible skin damage and some eye disorders (1). Queensland, Australia due to its low latitudes and relatively clear skies has high levels of ambient solar UV and has the highest incidence rates of non-melanoma skin cancer and cutaneous malignant melanoma in the world (2). Terrestrial UV is comprised of UVA (320-400 nm) and UVB (280-320 nm). The harmful effect of solar ultraviolet radiation on human skin is wavelength dependent and may be assessed using the concept of erythemally effective irradiance, UV_{ery}, defined as:

$$UV_{ery} = \int_{uv} S(\lambda)A(\lambda)d\lambda \qquad (1)$$

where A(λ) is the action spectrum for UV induced skin erythema in humans (3) and the integration is over the relevant wavelength range (280-400 nm). The relative sensitivity of the action spectrum is normalised to unity for wavelengths shorter than 290 nm. The sensitivity drops by about three decades with increasing wavelength for the UVB waveband (280-320 nm). In the UVA waveband (320-400 nm), the value varies from 10^{-3} to 10^{-4}. However, if solar UVB is removed with a barrier, for example, glass (4), then the UVA wavelengths provide significant exposure to erythemal UV. Repetitive exposure to UVA provides a cumulative effect and causes damage to human skin (5-7). UVA has also been reported as causing photoaging of human skin (8).

The optical transmittance properties of various automobile glass, windscreens and automobile window tints have been reported (9, 10). The angle of the solar radiation on the glass also affects the UV transmission through glass due to changes in the percent reflected and changes in the optical pathlength through the glass (11). No data on personal UVA exposure to specific body sites of humans in a vehicle is available for analysis of the health hazards. Even with the side windows fully wound up, for persons driving or for passengers undertaking continuous, long hours in a vehicle on the lengthy road distances in Australia may receive substantial cumulative exposures to erythemal UV radiation from the UVA component filtered through the side and back windows and the windscreen glass. The automobile roof provides a considerable degree of shading, however, automobile passengers and drivers may be exposed to both the direct and diffuse components of UVA. This is dependent on the direction of travel and the solar zenith and azimuth angles. Alternatively, even if shaded by the roof or other structural components of the vehicle, the driver or passengers may still be exposed to the diffuse component of UV radiation which may be often at least 50% (12) of the global irradiance.

Conventional dosimetric, radiometric and spectroradiometric techniques are both impractical and not feasible for the measurement of filtered solar UV radiation in a car. Current scientific data is not sufficient for assessing the hazard of filtered UV radiation to humans in the environment of a car. Previous research has employed a spectrum evaluator based on dosimetric materials for measuring the erythemal exposure due to filtered UV radiation (13, 4) and the erythemal UV exposure in a glass greenhouse (14). This paper provides previously unavailable data on the exposure to filtered erythemal UV to specific human body sites inside a car for the assessment of the UV hazard.

Materials and Methods

UVA Irradiances

The UVA irradiances were measured with a detector (Model 3D V2.0, Solar Light Co., Philadelphia, USA) in two late model cars with the side windows fully wound up and with no additional window tinting apart from that provided by the manufacturer. The detector was fitted with a sensor for measuring UVA irradiances and a sensor for measuring the erythemally weighted irradiances. A car was selected from the large family class (1997 model Ford Falcon Gli) and from the small car class (1997 model Ford Festiva Trio S). In Australia, cars have the driver's seats on the right and travel on the left hand side of the road. In this paper, these will be referred to as car F and car S respectively. The windows on car F had the manufacturer's tint (Smart tint, EZ-Kool) whereas the car S windows were untinted. Both cars were parked facing west as shown in Figure 1.

The data was collected in Toowoomba, Australia (27.5^{o} S latitude), on 15 August, 1997 in the morning, noon and afternoon at 9:00 Australian Eastern Standard Time (EST), 12:00 EST and 15:00 EST respectively. The solar zenith angle at noon was approximately 42^{o}. The entire day was relatively clear of cloud with only 1 octa of cloud at both 09:00 and 15:00 EST as recorded by a trained Bureau of Meteorology observer. The UVA irradiances in each of the cars at each of the times were measured in the front and back of the cars on the driver and passenger sides at the sites FD, FP, BD, BP (Figure 1) at a height of 43 cm above the seats and on the steering wheel (site S) on a horizontal plane. The UVA irradiances behind the side and back windows and behind the windscreen at an orientation normal to the glass were also measured at the sites FDW, FDF, FPF, FPW, BPW, BPB, BDB and BDW (Figure 1). The UVA irradiances and the erythemal irradiances, UV_{ery} outside the car on a horizontal plane were measured with the Solar Light detector.

In order to investigate the effect of orientation of the cars, car S was also orientated facing to the north and the UVA irradiances measured at the sites in the car described above.

Personal Erythemal UV Radiation

There are practical and logistical difficulties in attempting to simulate the complex range of human movements and body shapes. In this paper, a simplified approximation has been employed, namely, a mannequin with movable joints was seated in the drivers seat of car F and car S on 25 August, 1997 (Figure 2). The solar zenith angle at noon was approximately 38^o. A spectrum evaluator was deployed at seven sites on each mannequin, namely, on the chin, right and left sides of the face, nose, right mid-arm, right hand and right shoulder. One set of spectrum evaluators were exposed for the morning period of 9:00 to 12:00 EST and a second set from 12:00 to 15:00 EST. Both cars were parked facing to the west with the windows wound up. The cloud cover was 1 octa at 9:00 EST and zero octa at 15:00 EST. The spectrum evaluators were analysed and the erythemal exposures received at each site evaluated as described elsewhere (4). At 9:00, 12:00 and 15:00 EST the ambient UVA and erythemal irradiances outside the car on a horizontal plane were measured with the Solar Light detector.

Results

UVA Irradiances

The UVA irradiances in both car F and car S at the three times are provided in Table 1. The letter in parentheses (W or N) denotes the direction of the front of the car. The irradiances in the cars at each site vary with time of day, the type of car and for a given car, the direction. The UV irradiances in the larger car are specific to the manufacturer's tint on the window glass. The UVA transmission of the glass is provided by the irradiances measured directly behind and normal to the window glass at the FDW and BDW sites. At noon, these were 1.0 mW cm^{-2} for car F and 3.3 to 3.4 mW cm^{-2} compared to the ambient irradiance of 4.1 to 4.2 mW cm^{-2}. The UVB irradiances behind the glass were negligible in both cases. For some sites, the maximum in the UVA irradiance may not necessarily occur at noon. For example, the FD site for car S(N) has a higher irradiance of 1.5 mW cm^{-2} at 9:00 EST compared to 0.6 mW cm^{-2} at 12:00 EST. This is due to the orientation of the car with respect to the sun causing shading to that site at noon. The UVA irradiances in car S are higher than those in car F with the highest irradiances to any of the sites of 0.6, 1.0 and 0.5 mW cm^{-2} at 9:00, 12:00 and 15:00 EST respectively in car F compared to 2.3, 3.4 and 1.7 mW cm^{-2} in car S. The range in the variation of the irradiances over the sites in the cars is larger for car S. These differences in the two cars are due to the tint provided as standard by the manufacturer in the larger car F.

This is further highlighted in Table 2 where a number of ratios have been calculated for the average of the irradiances at all the sites and the average of the irradiances on a horizontal surface and the average of the irradiances behind the side window glass.

For the two cars parked in the same direction, namely, towards the west, averaged over all the sites, car F receives 0.27 to 0.4 of the irradiances in car S. The ratio of the irradiances averaged over all sites inside the car compared to the UVA irradiances outside the car on a horizontal surface ranges from 0.11 to 0.13 over the day. In comparison, the same ratio for car S ranges from 0.32 to 0.45. Higher irradiances are experienced at the sites through the side window glass with irradiances of 0.48 to 0.58 the UVA irradiances outside the car.

Personal Erythemal UV Radiation

The erythemal UV irradiances to each of the body sites for the morning and afternoon periods have been employed in Table 3 to provide the exposures to the body sites for the six hour period from 9:00 to 15:00 EST. These are due to the filtered solar radiation, mainly UVA radiation, as there is negligible UVB radiation in the cars with the windows fully up. This is confirmed both by the negligible change in the absorbance of the polysulphone material in the spectrum evaluator and the measurements with the Solar Light detector.

For car F, the erythemal exposures range from 0.22 for the nose to 1.5 mJ cm^{-2} for the right mid-arm. In comparison, for car S, the exposures range from 0.49 for the nose to 3.1 mJ cm^{-2} for the right shoulder. In general, the erythemal exposures to each of the sites for car S are two to three times more than those for the corresponding human body sites in car F. The only exception to this is the right mid-arm site in car S which receives less than the corresponding site in car F. This may be due to shading of this site by the door in the smaller car.

In both cars the smallest exposure was to the nose. This may be due to the angle of the nose at approximately 45^{o} to the horizontal and pointing towards the roof of the car whereas all of the other sites are approximately either horizontal or vertical. The highest exposure was received to the right mid-arm in car F and right shoulder in car S. The higher exposures of these two sites are due to the proximity to the side window glass. The right side of the face received 2.3 times higher exposure than the left side of the face in car F and 3.7 times higher exposure in car S.

The erythemal exposure to a horizontal surface outside the cars between 9:00 and 15:00 EST obtained by interpolating between the three measurement points of 9:00, 12:00 and 15:00 EST with the Solar Light detector was 210 mJ cm^{-2}. The erythemal irradiances in the cars are a significant reduction in this exposure. In terms of a minimum erythemal dose (MED) corresponding to 20 mJ cm^{-2} (15) where one MED is the erythemal exposure to produce barely perceptible reddening after a period of 8 to 24 hours, the right shoulder site in car S received 0.16 MED over the six hour period.

Conclusion

The erythemal UV exposures inside two cars has been measured employing a spectrum evaluator based on dosimetric materials that provides the time integral of the cumulative exposure. The cumulative erythemal exposure over any period to any site on a human in a car results from a combination of shade and filtered sunlight. The method allows the exposure over a six hour period to be evaluated and provides previously unavailable data on the erythemal exposure in a car.

From the findings of this research on the human body distribution of erythemal UV in a car, there is a higher erythemal UV to a human in the car without the manufacturers tint on the windows. In car S the highest exposure site received 2.2 times more exposure than the highest exposure site in car F. In both cars, the highest erythemal exposures to the body sites are to the body region of the right shoulder, arm and hand. The right side of the face receives a higher exposure than the left side of the face by a factor of 2.3 to 3.7. Although less than the threshold exposure of one MED, the exposure of 0.16 MED over the six hour period to the right shoulder in the smaller car without the manufacturers tint means that protective measures are still required as previous research has shown that suberythemal exposures to UV radiation have a cumulative damaging effect.

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Table 1 - The UVA irradiances at the sites in each of the cars at each of the times.

		UVA Irradiances (mW cm^{-2})								
		morning			noon			afternoon		
Site	Orientation	Car F (W)	Car S (W)	Car S (N)	Car F (W)	Car S (W)	Car S (N)	Car F (W)	Car S (W)	Car S (N)
FD	Horizontal	0.3	1.3	1.5	0.7	2.4	0.6	0.2	0.5	0.5
FP	Horizontal	0.1	0.2	0.4	0.1	0.2	0.7	0.2	0.5	1.1
BD	Horizontal	0.1	0.4	0.8	0.7	2.4	0.3	0.4	1.1	0.2
BP	Horizontal	0.3	1.0	0.2	0.1	0.3	0.3	0.1	0.2	1.2
S	Horizontal	0.2	0.9	0.4	0.3	0.6	0.6	0.2	0.4	0.3
FDW	To glass	0.5	2.0	2.3	1.0	3.3	0.6	0.5	1.7	0.5
FDF	To glass	0.1	0.1	0.6	0.3	0.5	0.8	0.4	0.6	0.3
FPF	To glass	0.1	0.1	0.5	0.3	0.4	0.8	0.4	0.5	0.5
FPW	To glass	0.1	0.5	0.6	0.2	0.6	1.9	0.2	0.5	2.3
BPW	To glass	0.1	0.5	0.5	0.2	0.6	2.1	0.2	0.5	2.3
BPB	To glass	0.6	2.1	0.5	0.4	1.7	0.6	0.2	0.5	0.5
BDB	To glass	0.6	2.2	0.5	0.5	1.9	0.6	0.2	0.6	0.5
BDW	To glass	0.6	2.3	1.9	1.0	3.4	0.6	0.5	1.7	0.5

Table 2 - The ratios of car F(W)/car S(W) irradiances, car F(W) irradiances/UVA irradiance outside the car and car S(W) irradiances/UVA irradiance outside the car. The irradiances inside the cars have been averaged over all the sites, the horizontal sites only and the sites behind the side windows.

	Car F(W)/Car S(W)			Car F(W)/outside			Car S(W)/outside		
	mor-ning	noon	after-noon	mor-ning	noon	after-noon	mor-ning	noon	after-noon
All sites av.	0.27	0.32	0.40	0.12	0.11	0.13	0.45	0.34	0.32
Horizontal sites av.	0.26	0.32	0.41	0.09	0.09	0.10	0.33	0.28	0.24
Side window sites av.	0.25	0.30	0.32	0.14	0.14	0.16	0.58	0.48	0.49

Table 3 - The erythemal exposures to the various mannequin sites for the six hour period.

	Erythemal exposures (mJ cm^{-2})	
Site	Car F(W)	Car S(W)
Chin	0.24	0.79
Right side of face	0.60	2.2
Left side of face	0.26	0.60
nose	0.22	0.49
Right mid-arm	1.5	0.86
Right hand	1.3	2.5
Right shoulder	1.3	3.1

FIGURE CAPTIONS

Figure 1 - Orientation of the cars and the measurement sites inside the cars.

Figure 2 - Photograph of a mannequin with the spectrum evaluators attached.

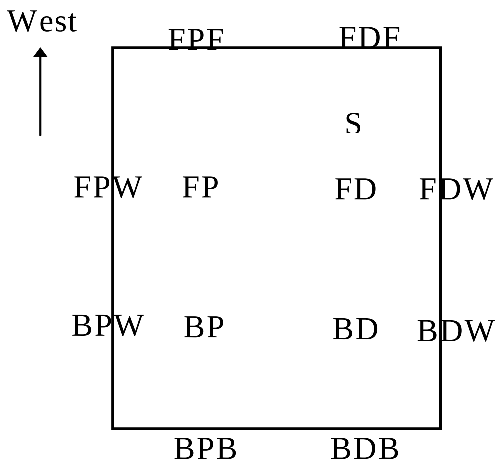

Figure 1

Figure 2