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# Quantitative evaluation of the personal erythemal ultraviolet exposure in a car

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Erythemal ultraviolet (UV)-radiation exposure to the right hand, mid-arm, shoulder, chin, nose and left and right sides of the face has been evaluated in a car from a large family class and a car from a small car class. In the small car, the site with highest exposure received 2.2 times more radiation than the site with the highest exposure in the larger car. In both cars, highest erythemal exposures were to the right shoulder, arm, and hand. Over a 6 h period, erythemal exposure to the right shoulder of a person in the driver's seat of the small car was 3.1 $mJ \cdot cm^{-2}$.

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Exposure to harmful solar ultraviolet (UV) radiation is linked to the incidence of skin cancer, 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 the highest incidences 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) radiation. The harmful effect of solar UV 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 $A(\lambda)$ 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. Sensitivity drops by about three decades, with increasing wavelength for UVB. In the UVA region, this 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 may 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 window tints have been reported (9, 10). The angle of the solar radiation on the glass also affects UV transmission through glass due to changes in reflectance and changes in the optical pathlength (11). No data on personal UVA exposure to specific body sites of humans while in vehicles is available to guide health hazard analyses. Even with side windows fully wound up, drivers and passengers undertaking long journeys in Australia may receive substantial amounts of erythemal UVA radiation through side and back windows and windscreen glass. Although the automobile roof provides considerable shading, passengers and drivers may be exposed both directly and indirectly to UVA radiation. This is dependent on the direction of travel and the solar zenith and azimuth angles. Even when shaded by the roof and other structural elements in the vehicle, the driver or passengers may still be exposed to the diffuse component of UV radiation that may be 50% (12) of the global irradiance.

Conventional dosimetric, radiometric and spectroradiometric techniques are impractical when measuring filtered solar radiation in automobiles, and the available scientific data is insufficient to assess the hazard of filtered UV radiation. Previous research has employed a spectrum evaluator based on dosimetric materials to measure erythemal exposure from filtered UV radiation (4, 13) and erythemal UV exposure in a glass greenhouse (14). Herein we present new data on filtered erythemal UV received by specific human body sites inside a car, allowing assessment of the UV hazard.

## Material and methods

### UVA irradiances

UVA irradiance was measured with a detector (Model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) in two late model cars with the side windows fully closed and with no additional window tinting apart from that provided by the manufacturer. The detector was fitted with a sensor for measuring UVA irradiance and a sensor for measuring the erythemally weighted irradiance. 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 Fig. 1.

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

In order to investigate the effect of orientation, car S was also oriented facing north, and UVA irradiance was again measured as described above.

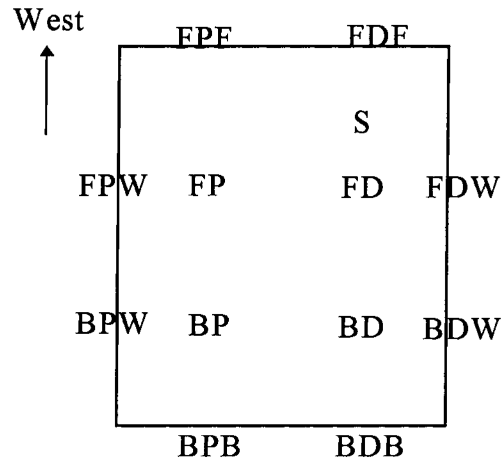


*Fig. 1.* Orientation of the cars and the measurement sites inside the cars.

*Fig. 2.* Photograph of a mannequin with the spectrum evaluators attached.

### 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 was employed, namely, a mannequin with movable joints was seated in the driver's seats of each car on 25 August, 1997 (Fig. 2). The solar zenith angle at noon was approximately 38°. A spectrum evaluator was deployed at seven sites on each mannequin: chin, right and left sides of the face, nose, right mid-arm, right hand and right shoulder. One set of spectrum evaluators was 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 the west with the windows closed. 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

Table 1. UVA irradiance at the sites in each of the cars at each of the times

| | | UVA irradiances ($mW \cdot cm^{-2}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

*Direction of car heading: W (west), N (north).

Table 2. Ratios of car F(W)/car S(W) irradiance, car F(W) irradiance/UVA irradiance outside the car and car S(W) irradiance/UVA irradiance outside the car. Irradiance inside the cars has 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 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Morning | Noon | Afternoon | Morning | Noon | Afternoon | Morning | Noon | Afternoon |
| 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 |

ambient UVA and erythemal irradiance outside the car on a horizontal plane were measured with the Solar Light detector.

## Results

### UVA irradiances

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

Table 2 compares the two cars by calculating ratios for the average of irradiance at all sites, the average of irradiance on a horizontal surface, and the average of the irradiance behind the side window glass. For the two cars parked towards the west, averaged over all the sites, car F received 0.27 to 0.4 of the irradiance of car S. The ratio of the irradiance averaged over all sites inside the car compared to the UVA irradiance outside the car on a horizontal surface ranged from 0.11 to 0.13 over the day. In comparison, the same ratio for car S ranged from 0.32 to 0.45. Higher irradiance

Table 3. The erythemal exposures to various mannequin sites over 6 h

| | Erythemal exposures ($mJ \cdot cm^{-2}$) | |
|---|---|---|
| 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 |

occurred through the side window glass with irradiances of 0.48 to 0.58 of the UVA irradiance outside the car.

### Personal erythemal UV radiation

Erythemal UV irradiance to each body site for the 6 h period from 9:00 to 15:00 EST are listed in Table 3. These are due mainly to 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 measurements with the Solar Light detector.

For car F, erythemal exposures ranged from 0.22 (nose) to 1.5 $mJ \cdot cm^{-2}$ (right mid-arm). In comparison, for car S, the exposures range from 0.49 (nose) to 3.1 $mJ \cdot cm^{-2}$ (right shoulder). In general, erythemal exposure to each site for car S was two to three times higher than that of each body site in car F. The only exception was the right mid-arm site in car S, which received 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 lowest exposures were to the nose. This may be due to the angle of the nose (approximately 45° to the horizontal), whereas all of the other sites were approximately either horizontal or vertical. The highest exposure was received by the right mid-arm in car F and right shoulder in car S. High exposures to these two sites are due to the proximity to the side window glass. The right side of the face received 2.3 times more exposure than the left side of the face in car F and 3.7 times more exposure in car S.

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 $mJ \cdot cm^{-2}$. The erythemal irradiance inside of the cars was significantly less. In terms of a minimum erythemal dose (MED) corresponding to 20 $mJ \cdot cm^{-2}$ (15), where one MED is the erythemal exposure that produces barely perceptible reddening after a period of 8 to 24 h, the right shoulder site in car S received 0.16 MED over a 6 h period.

## Conclusion

Erythemal UV exposures inside two cars were 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 6 h period to be evaluated and provides new data on the erythemal exposures in cars. There were higher levels of erythemal UV in a car without the manufacturer's tint on the windows. In this car (S), the site with highest exposure received 2.2 times more radiation than the highest site in car F. In both cars, the highest erythemal exposures were to the right shoulder, arm and hand. The right side of the face received 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 6 h period to the right shoulder in car S (without the manufacturer's tint) means that protective measures are still required, because previous research has shown suberythemal exposures to UV radiation to have a cumulative damaging effect.

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