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UV exposure in cars

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Background: **There is increasing knowledge about the hazards of solar and ultraviolet (UV) radiation to humans. Although people spend a significant time in cars, data on UV exposure during traveling are lacking. The aim of this study was to obtain basic information on personal UV exposure in cars.**

Methods: **UV transmission of car glass samples, windscreen, side and back windows and sunroof, was determined. UV exposure of passengers was evaluated in seven German middle-class cars, fitted with three different types of car windows. UV doses were measured with open or closed windows/sunroof of Mercedes-Benz E 220 T, E 320, and S 500, and in an open convertible car (Mercedes-Benz CLK). *Bacillus subtilis* spore film dosimeters (Viospor) were attached to the front, vertex, cheeks, upper arms, forearms and thighs of 'adult' and 'child' dummies.**

Results: **UV wavelengths longer than >335 nm were transmitted through car windows, and UV irradiation >380 nm was transmitted through compound glass windscreens. There was some variation in the spectral transmission of side windows according to the type of glass. On the arms, UV exposure was 3–4% of ambient radiation when the car windows were shut, and 25–31% of ambient radiation when the windows were open. In the open convertible car, the relative personal doses reached 62% of ambient radiation.**

Conclusions: **The car glass types examined offer substantial protection against short-wave UV radiation. Professional drivers should keep car windows closed on sunny days to reduce occupational UV exposure. In individuals with polymorphic light eruption, produced by long-wave UVA, additional protection by plastic films, clothes or sunscreens appears necessary.**

Key words: **car; dosimetry; glass, ultraviolet radiation.**

The risks of solar and ultraviolet radiation (UVR) to humans are summarized in a monograph of the International Agency for Research on Cancer (1) and are reviewed by Armstrong and Kricker (2). Today's mobile society spends a significant time in cars. However, profound data on UV exposure while traveling or working in cars are lacking. In the literature, there are only two anecdotal reports on UV exposure in cars (3, 4).

The aim of this study was to obtain further information on personal UV exposure in cars. Protective measures are illustrated.

Materials and methods

UV transmission of different types of car window glass

UV transmission of glass samples (5 cm × 5 cm) of the different car windows [windscreen, back and side windows: insulative green glass (E-Class, E 320), insulative blue glass (E-Class, E 220 T), insulative infrared reflective glass (S-Class, S 500) and sunroof glass (E 320, E 220 T, S 500)] have been tested by spectrophotometry (280–390 nm) (UV-Vis Cary3Bio; Varian, Darmstadt Germany) (5). The mean transmission was calculated from four measurements of each glass type.

Simulated UV exposure during car driving

UV exposure in a circulating car is a complex product of changing directions, alternating light and shadow, and time. These conditions are difficult to simulate in a standardized manner. Therefore, the experiments were performed on standing vehicles, which were moved every 30 min by 7.5° in such a way that the sun was shining at right angles to the driver's side. As a result, the left car side (driver's side) had maximum sun exposure and the right car side had no direct sun exposure. The cars were positioned sufficiently apart to allow full sun exposure of each car.

On 17 July 2000 from 9:00 to 17:00 h and on 19 July from 7:30 to 17:40 h MEST, the measurements were performed on an open concrete surface in Sindelfingen, Germany (443 m above sea level, 48°42′35″ northern latitude; 9°00′23″ longitude) under unclouded sunny conditions.

Dosimeters

UV doses were recorded by *Bacillus subtilis* spore film dosimeters (VioSpor; BioSense). The dosimeter system is enclosed in an aluminum capsule with a diameter of 32 mm, a thickness of 9 mm and a weight of 15 g. Preparation and processing of the spore film detectors (VioSpor, Blue Line Type II and III, BioSense, Bornheim, Germany) were performed as described previously (6, 7). The dosimeter system (VioSpor) integrates the UVR effect over the whole spectrum in the solar UVB and UVA region (290–380 nm) with a good correlation with the reference spectrum of the Commission Internationale d'Éclairage (CIE) (6, 8, 9). Thus, the sensitivity of a spore film dosimeter represents the action spectrum for erythema reaction in human skin.

The 'biologically effective dose', derived from radiant exposure weighted by such an action spectrum, is expressed in units of J/m^2 (effective) or as multiples of 'minimal erythema dose' (MED). One MED has been defined as the lowest radiant exposure to UVR that is sufficient to produce erythema with sharp margins 24 h after exposure. When the term MED is used as a unit of exposure dose, a representative value is chosen for sun-sensitive individuals (1). The MED will vary according to the wavelength range over which the effective UVR is summed and for radiation protection purposes is generally taken in the range 200–300 J/m^2 to be effective (10). The UV doses measured by the spore film dosimeters are given in 'biologically weighted' MED. One MED corresponds to 250 J/m^2.

Threshold limit values (TLV) are issued at defined wavelengths but also as an effective dose. The TLV in terms of effective dose is 30 J/m^2 per 8-h workshift when using the American Conference of Governmental Industrial Hygienists (ACGIH) action spectrum (11) corresponding to 109 J/m^2 per 8-h workshift (0.43 MED) using the CIE action spectrum (Jan Laperre, personal communication, 2002).

Cars and dummies

On 17 July 2000 from 9:00 to 17:00 h and on 19 July from 7:30 to 17:00 h MEST UV exposure of passengers was evaluated in three identical pairs of German, middle-class cars (Mercedes-Benz E 220 T, E 320, S 500; DaimlerChrysler AG, Sindelfingen Germany). These models were fitted with three different types of car windows [insulative green glass (E-Class, E 220 T, sunroof), insulative blue glass (E-Class, E 320, without sunroof), insulative infrared reflective glass (S-Class, S 500, sunroof)], with windows and sunroof closed and opened, respectively.

Dosimeters were attached to the front, vertex, cheeks, thighs, upper arms and forearms of adult dummies on the front seats and child dummies on the back seats (Fig. 1).

UV dosimetry was performed in a similar way in one open convertible car (Mercedes-Benz CLK) on 19 July 2000 from 7:40 to 17:40 h MEST.

In order to simulate the situation of cars exposed to the sun at various angles for each car a mean UV dose was calculated from the UV exposure of the driver's left upper arm and the front-seat passenger's right upper arm.

Simultaneously, ambient radiation was registered with triplicate dosimeters (VioSpor Blue line Type III, BioSense, Bornheim, Germany) on a horizontal plane.

Results

UV transmision of different types of car window glass

Insulative green glass: Windscreens of this glass type blocked UV transmission of UV <375 nm more than 1000-fold; significant UV transmission started at 385 nm, reaching 11% at 390 nm. In back window glass, UV transmission started at 335 nm rising with a minor decrease between 370 and 385 nm to a maximum of 63% at 390 nm (averaged in the UVA range 315–380 nm: 17.5%). UV transmission of side windows (Fig. 2) was comparable to back window

Fig. 1. Personal dosimetry of adult dummies in a Mercedes-Benz E 220 T.

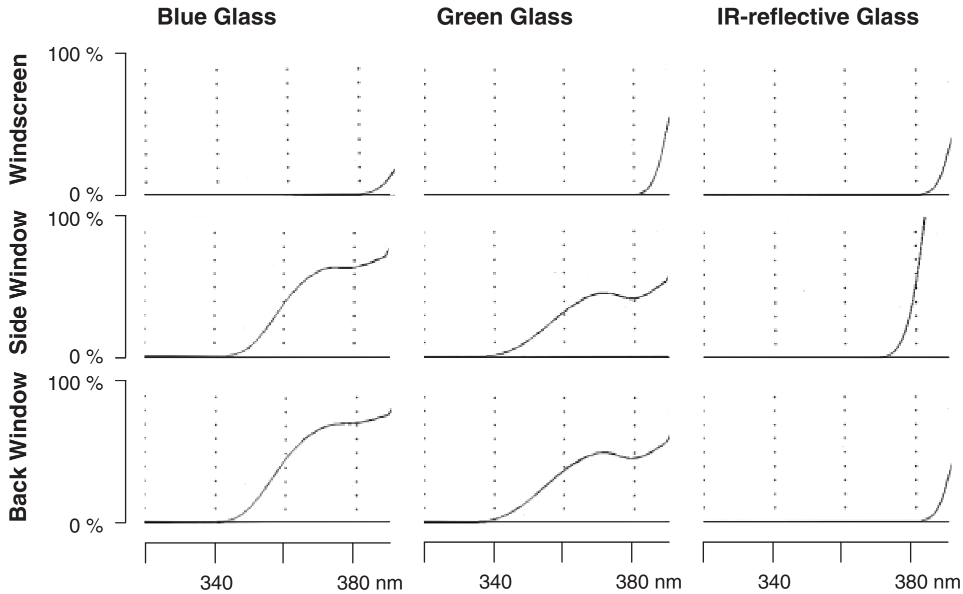

Fig. 2. Spectral transmission of car windows: (left) insulative blue glass (E-Class); (middle) insulative green glass (E-Class); (right) insulative infrared-reflective glass (S-Class).

glass, with a maximum of 58% at 390 nm [averaged in the UVA range (315–380 nm): 20.2%].

Insulative blue glass: There was <0.02% UV transmission in windscreen glass below 385 nm, with a maximum of 18% at 390 nm. In back window glass, there was a steep increase of UV transmission from 2.6% at 345 nm to 46% at 360 nm and 83% at 390 nm (averaged in the UVA range: 25.7%). Side windows (Fig. 2) had a UV transmission similar to back window glass with 79% at 390 nm (averaged in the UVA range: 17.5%).

Insulative infrared reflective glass: UV transmission >0.02% of windscreen and back window glass samples started at a wavelength above 385 nm, and was 9% at 390 nm. Side windows (Fig. 2) showed UV transmission from 375 nm upwards, reaching 50% at 390 nm (averaged in the UVA range: 0.8%).

Sunroof: From 335 nm upwards, sunroof glass was slightly UV transmissible reaching 15% transmission at 390 nm.

Windscreens (compound glass) of all glass types and sunroof glass were highly UV absorptive. There was some variation in the spectral transmission of side windows according to the type of glass. The spectral transmission was least in insulative infrared-reflective glass and higher within the UVA range in insulative green glass and insulative blue glass (Fig. 2). Only UV wavelengths >335 nm in car windows and >380 nm in windscreens (compound glass) were transmitted. The best UV absorption was found in insulative infrared-reflective glass.

Simulated UV exposure during car driving

Ambient radiation: Cumulative ambient UV irradiation over 2 days (17.5 h) was 49.4 MED. During the experiment with the convertible (1 day, 10 h), cumulative UV dose was 26.4 MED. UV exposure under those simulated conditions is given in percent of the total cumulative ambient dose.

Mercedes-Benz E 220 T (insulative green glass): The highest doses in the *closed* car of this type were found on the driver's left arm (forearm 6.2%, upper arm 4.6%) and the left child's left arm (forearm 4.1%, upper arm 5.2%), i.e. the sites that were closest to the car windows with highest sun exposure (Fig. 3a).

In the car with windows and sunroof *opened*, UV exposure on the driver's left upper arm and forearm, the left child's forearm, and the passenger's left upper arm and left lateral head exceeded the maximum capacity of the dosimeters used on these sites (>17 MED or >34%). Considerable UV doses were measured even on the passenger's side due to the opened sunroof and indirect UVR (passenger's front 22.1%, right upper arm 27.7%) (Fig. 3b).

Mercedes-Benz E 320 (insulative blue glass): In this car with windows *closed*, highest UV exposure was found on the left arms of the driver (forearm 5.9%, upper arm 6.7%) and the left child (forearm 12.6%, upper arm 7.1%). The stronger UV doses on the back seat might be explained by the window geometry, seat position and orientation of the dosimeter.

With windows *opened*, compared to the other car types, lower UV exposure was found on the dummies on the right side of the car, probably due to the

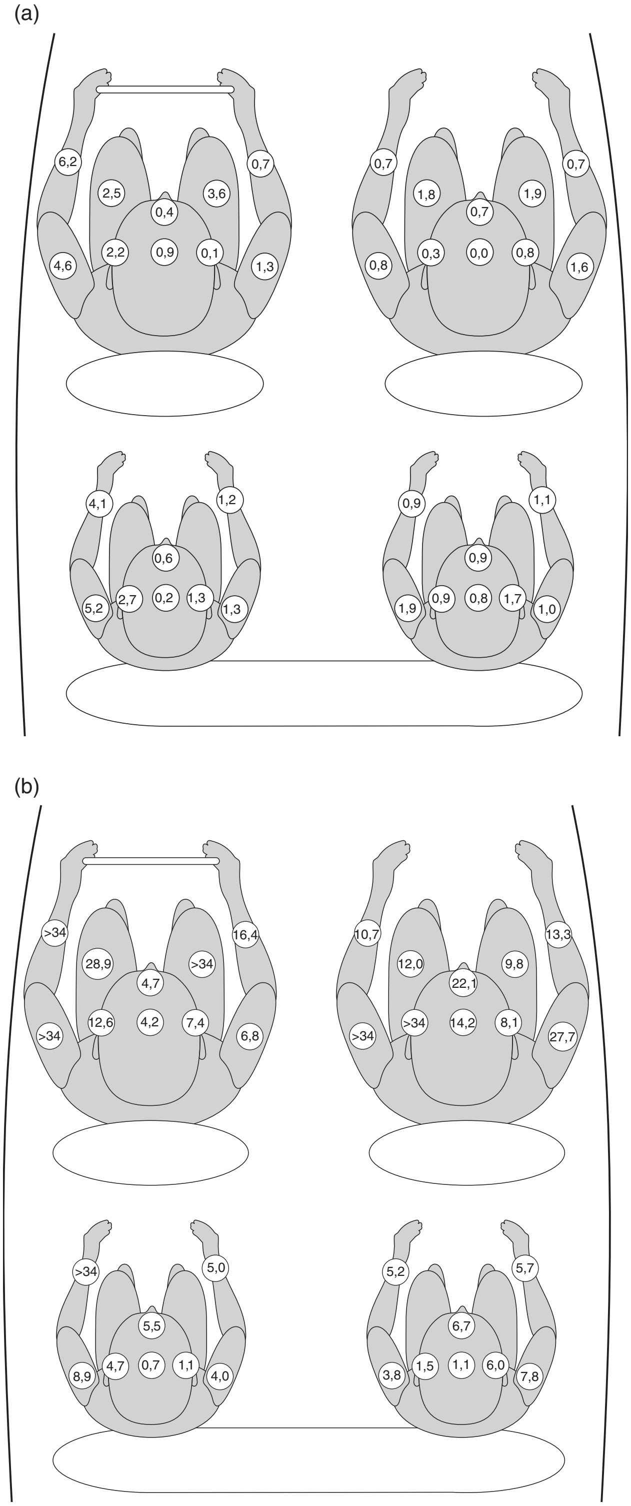

Fig. 3. UV exposure in a Mercedes-Benz 220 T, insulative green glass. Relative personal dose in % of ambient radiation, during a period of 17.5 h on 17 and 19 June 2000 at an ambient radiation of 49.4 MED. (a) With windows and sunroof closed; (b) with windows and sunroof opened.

missing sunroof in this type of car. However, on the driver's left arm and the left child's left forearm, the biofilm dosimeters had > 34% of the ambient cumulative dose corresponding to > 17 MED. Considerable UV exposure was found on the driver's left lateral head (31.0%) and right thigh (25.5%).

Mercedes-Benz S 500 (insulative infrared reflective glass): In the *closed* car, the highest UV dose was on the driver's left upper arm (5.1%), followed by the driver's left forearm (3.2%). The child on the left back seat received 2.2% of ambient radiation on the left forearm and 2.0% on the left upper arm. The difference might be explained by the lower position of the child dummy and the smaller size of the back door window.

With *opened* car windows and sunroof, dosimeters on the driver's left arm and the front-seat passenger's head were overexposed (> 17 MED or > 34%). The driver's right thigh received 29.8% of ambient radiation. Considerable UV exposure (24.3%) of the passenger's front, lateral head and upper arm, and the right child's upper arm was caused by the open sunroof. Indirect radiation through the open windows caused 15.2% of ambient radiation on the passenger's right upper arm and 4.9% of ambient radiation on the right child's right upper arm.

Mercedes-Benz CLK (convertible car): The most intense UV exposure was found on the driver's vertex (108%), and the lowest UV exposure was found on the right upper arm of the passenger (15.9%), a site without direct insolation (see Fig. 4). On the vertex of the driver and passenger as well as on the driver's arm, UV exposure exceeded ambient radiation.

The comparison of each dosimeter position in the different cars showed increasing UV exposure from insulative infrared reflective glass to insulative blue glass and insulative green glass. Therefore, the dosimetric measurements are in line with spectophotometric data from the different car glass types used.

In general, with windows closed the mean UV exposure (driver's left upper arm and front-seat passenger's right upper arm averaged over 2 days) was 0.08 MED/h (insulative infrared reflective glass), 0.09 MED/h (insulative green glass), and 0.1 MED/h (insulative blue glass), corresponding to a relative personal dose of 3–4% of ambient radiation.

With windows opened the mean UV exposure (averaged over two days) exceeded 0.7 MED/h (insulative infrared reflective glass and insulative blue glass) and 0.9 MED/h (insulative green glass), corresponding to > 25–31% of ambient radiation.

In the open convertible, there was a mean personal exposure of 1.8 MED/h (max 3.2 MED/h), i.e. 62% of ambient radiation (max. 108%).

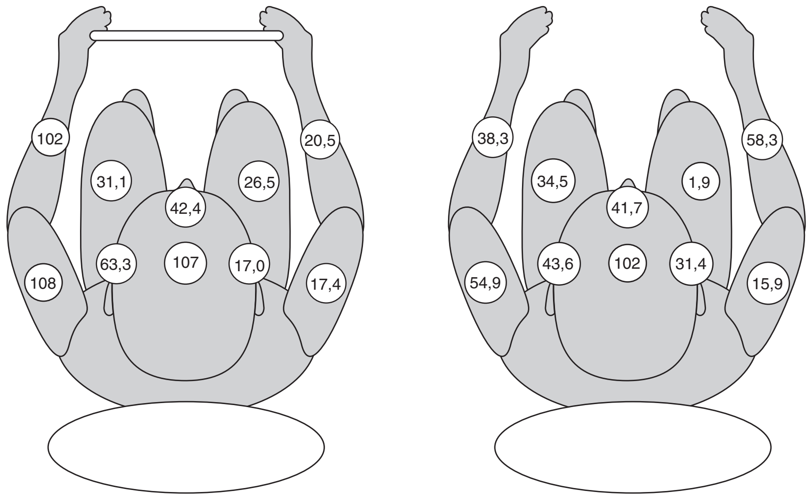

Fig. 4. UV exposure in a Mercedes-Benz CLK convertible. Relative personal dose in % of ambient radiation, during a period of 9 h on 19 June 2000 at an ambient radiation of 26.4 MED.

Discussion

In many countries, programs have been initiated to protect individuals against solar UVR. For outdoor workers in Australia, for example, this has meant the provision of hats, sunglasses, protective clothing and sunscreens (12). Such programs did not always apply to car and truck drivers. It has been suggested that the higher incidence of solar keratoses on the right arm in Australian men might be caused by sun exposure while driving (13). Moreover, it has been proposed that drivers may benefit from a reduced solar UV exposure if the vehicle windows were tinted (12, 14) or coated with a nonreflective plastic film (14).

In this study, UV transmission of car glass samples used for Mercedes-Benz cars was determined by spectrophotometry. None of the car glasses of the cars studied showed UV transmission in the UVB range. Windscreens, which were made of compound glass, of all glass types and sunroof glass had minimal UV transmission. Side windows (and back windows) of various glass types showed different spectral transmittance: the average transmission in the UVA range was 17.5% (20.2% for back windows) in insulative green glass, 22.4% (25.7% for back windows) in insulative blue glass and 0.8% (0% for back windows) in insulative infrared reflective glass (Fig. 2). The spectrophotometric data demonstrate that in cars with windows closed only UVA radiation could be detected.

An Australian study on UV protection factors for clear and tinted automobile windscreens did not find any UV transmission in the UVB range either. In the UVA range, transmission was between 2.1% and 70% (15). There was a considerable variation in the UV transmission of glass. UV transmission of glass decreases with decreasing wavelength, yet some glass types were penetrated even by UVB. UV transmission depended on the type of tinting and thickness of glass (3, 12, 14–16). Polycarbonate sheeting provided excellent protection as it is a strong absorber of UVR (12). A variety of nonreflective plastic films for car windows are available from professional applicators and do-it-yourself kits. Such films show a cut-off point at 370 or 380 nm (14).

In accordance with the Australian study by Gies et al. (15), we conclude that UV transmittance of car glass varies considerably depending on the type of glass, thickness, tinting and reflective coating. The car glass of this study had low UV transmittance. Windscreens of Mercedes-Benz E-Class and S-Class models had less UV transmittance than has been reported for other types of windscreens in the literature (14, 15). Nevertheless, UV protection of side and back windows could still be improved.

We have not tested luminous transmittance of the Mercedes-Benz car glass samples. In various countries, there are coloration limits for windscreens. It remains unclear as to how tinted sunglasses worn by drivers and tinted car glass may interact and thereby affect color perception and reaction time.

Corresponding to the spectrophotometric measurements, cars with insulative infrared reflective glass showed the best protection of passengers against UVR followed by insulative green glass and insulative blue glass.

In all *cars with windows/sunroof closed*, the highest UV exposure was found on the left arm and left lateral head of the driver and the left child dummy (maximum 6.7 MED, 13.6% of ambient radiation). On the right arms of dummies at the passenger side, which were oriented away from the sun, an exposure between 0.1 and 0.8 MED (2.0% of ambient radiation) was measured, showing good protection of the car glass against diffuse radiation.

In the *cars with windows/sunroof opened*, the maximum exposure exceeded the capacity of the dosimeters used (>17 MED, >34% of ambient radiation). The most important erythemogenic radiation was detected on the left arms of the driver and on the left back-seat passenger. With sunroof opened, passengers on the right side received considerable UVR on the left arm and head. On the right upper arm of the front passenger, UV exposure was about 7.5–13.7 MED (15.2–27.7% of ambient radiation), resulting from indirect radiation (UVA/UVB) mostly through the open side window.

Unexpectedly, in the convertible on the vertex of the driver and passenger as well as on the driver's arm, UV exposure exceeded ambient radiation, due to the orientation of the dosimeter with a higher proportion of direct radiation.

A mean UV exposure was calculated from the readings on the left arm of the driver and the right arm of the passenger to simulate a turning car. With windows closed, the mean UV exposure was 3–4% of ambient radiation. With windows opened, the mean UV exposure exceeded 25% of ambient radiation. In the open convertible car, a mean UV exposure of 61.4% of ambient radiation was found. On the 2 days of the experiment there were extremely sunny conditions.

Parallel to the measurements on the site in Sindelfingen with triplicate VioSpor Blue line Type III dosimeters, we performed a model calculation in cooperation with Dipl. Met. Henning Staiger from 'Deutscher Wetterdienst' Freiburg (German Meteorological Service). Calculations were based on weather data of the synoptic station 'Stuttgart Airport' as well as ozone data of the TOMS instrument (Total Ozone Mapping Spectrometer) of NASA of the satellite Earth Probe. For the measurement period on 17 and 19 June 2000, a cumulative UV dose of 35.4 MED (average 2 MED/h) was calculated. For the convertible experiment on 19 June 2000, there was a calculated cumulative UV dose of 18.9 MED (2.1 MED/h).

The difference between the ambient radiation measured by spore film dosimeters and the ambient radiation calculated from weather data may be explained by the fact that the former was a 'measurement' with a biological dosimeter system and the latter a model calculation.

UV exposure in cars will vary with ambient radiation, UV intensity (day time, geographic and meteorological conditions), angle of incident UVR due to the orientation of the car to the sun, whether windows are closed or not, the subjects' position (e.g. driver) and personal protection by clothing or sunscreen (12, 15–17).

The present study simulated UV exposure in cars in a standardized setting. In the literature there are only two anecdotal reports on UV exposure in cars. In 1994, Diffey tested a novel electronic UV dosimeter while driving in southern France. During a 63-min trip in the western direction in the morning, he registered on the driver's right arm (British car) a maximum UV dose of 2.31 MED/h and an average dose of 0.41 MED/h (4). Parisi and Wong (3)studied UV exposure in a small car (Ford Fiesta Trio S 1997) with untinted windows and in a middle-class car (Ford Falcon Gli 1997) with tinted windows. In each car, one dummy was posted on the driver's seat (right side). Polysulfone dosimeters were attached to the dummy's cheek, right and left face, nose, right shoulder, right upper arm and hand. The cars were oriented in a western direction from 9:00 to 15:00 h. On corresponding areas, UV exposure was two to three times higher in the small car with untinted windows. UV exposure was lowest on the nose and highest on the right arm and right shoulder. During the 6-h period in the small car, 0.16 MED had been measured on the right shoulder (3).

In contrast to the setting by Parisi and Wong, in this study the cars had been moved in order to have maximum solar radiation on one side of the car (driver's side; left) and minimum exposure on the other (right) side. Thus minimum and maximum exposure was determined and an averaged UV exposure (as a fraction of ambient radiation) was calculated.

Hereby, our data on UV exposure in cars obtained at 48° northern latitude at a UV index of 7.4 (17 June 2000) and 8 (19 June 2000) can be transferred to other locations with different UV indices.

For a professional driver in a car *with windows closed*, an annual UV exposure of about 35 MED has been estimated (220 working days; ambient radiation in Munich 1999: 2000 MED (18); 24.8% relative personal dose), which is comparable to a 1-week skiing trip (19). UV exposure considerably increases if windows/sunroofs are opened.

Very sun-sensitive individuals may not be sufficiently protected by car windows. Due to UVA transmission of car windows (especially side windows), additional protection, such as clothing and sunscreens, may be necessary for patients with polymorphic light eruption (PMLE) or phototoxic dermatitis (20). Johnson and Fusaro (14) produced an algorithm for diagnosis and tratment of photosensitive individuals using the absorption properties of car windows and nonreflective plastic films.

Using the CIE action spectrum TLV for an 8-h workshift (0.43 MED) (11) (Jan Laperre, personal communication, 2002), on a sunny day a professional driver will exceed the TLV for UVR when windows are shut and he is constantly oriented to the sun. On the other hand, the TLV can be reached even without direct sun exposure by indirect radiation through an opened car window.

In conclusion, the car windows with insulative green glass, insulative blue glass and insulative infrared reflective glass currently used in Mercedes-Benz E-Class and S-Class models offered good UVB and UVA protection to car passengers. However, on sunny days the recommended exposure limit for occupational UV exposure (11) could be exceeded.

UV protection of side and back windows still needs improvement. Professional drivers should keep car windows closed and use air conditioning to reduce occupational UV exposure. For very photosensitive individuals, additional protection by plastic films, clothing and sunscreens is necessary.

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