Seasonal variation of facial UV exposures in the shade

Subtitle: Seasonal changes in the personal distribution of UV beneath a common public shade structure

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Abstract

The personal distribution of solar erythemal UV exposures to the face, head and neck was investigated for a public shade structure in the seasons of winter and summer. Calculated personal erythemal UV exposures in the shade during winter ranged from 0.3 SED per day for the top of the head to 1.8 SED per day for the chin. In comparison, erythemal UV exposures in the shade during summer ranged from 0.3 SED per day for the top of the head to 4.6 SED per day for the chin. Broadband global and diffuse erythemal UV was also measured on a horizontal plane in the open at five minute intervals during the winter and summer period. Cumulative daily global and diffuse erythemal UV exposures for winter were 22±3.8 SED and 14±3.0 SED, respectively. While, cumulative daily exposures for summer were 55±13.6 SED and 42±3.1 SED for global and diffuse erythemal UV respectively. From this research it can be concluded that anyone seeking shade under this common public shade structure for an extended period of time requires additional protection measures against damaging UV radiation.

Keywords: erythemal UV; shade; dosimeter; diffuse; exposure

INTRODUCTION

Excessive and repeated exposures to any UV radiation source can cause serious damage to the human eyes and skin. As a result, it is essential to decrease any exposure to damaging solar UV radiation that the population experiences. This necessitates the need to assess the different environments that humans use and the subsequent UV radiation exposures they may receive during daily activities.

Personal UV exposure is due to sunlight received as both direct and diffuse (scattered) UV radiation. Diffuse UV constitutes a significant contribution of the UV exposure to human eyes and skin as is it is incident from all directions and difficult to minimize with the usage of hats, tree shade and shade structures (1-3). Behavioural influences also determine the amount of UV exposure the body receives, be it from suntanning, playing sport, gardening or other activities. It has been shown that subjective comfort has a determining influence on the rates of sunburn, with people exposing more and more skin as they become hotter due to rising ambient temperature levels (4). However, people will also stay out of the sun when the temperatures reach extreme levels where discomfort occurs. As people become better informed about the damaging effects associated with exposure to UV, shaded environments will be sought to reduce UV exposure levels (3,4). It is not often appreciated that people sheltering under trees or shade structures are exposed to a considerable amount of scattered UV radiation (3,6,7). While there are numerous guidelines for the design of various shade environments (for example 8-12), most forms of shade still offer people insufficient protection from UV radiation. Therefore, a need exists for more detailed research on the interaction of UV radiation with shade environments and subsequent ways to reduce personal UV exposure in the shade.

The use of different forms of shade is an essential part of a UV minimisation strategy (13). While shade reduces the direct component of global (direct and diffuse combined) UV, the proportion of diffuse UV present in the shade can still be significantly high (7,14-16). The research presented in this paper extends the previous research to provide an assessment of the levels of erythemal UV that people can be exposed to while utilizing the shade of a commonly employed shade structure.

EXPERIMENTAL

Seasonal global and diffuse erythemal UV

Global and diffuse erythemal UV on a horizontal plane were measured with a broadband UV meter (model 501, Solar Light Co., Philadelphia, USA) mounted on an unobstructed roof of the University of Southern Queensland, Toowoomba (lat 27.5^{o}S, long 151.9^{o}E), Australia. The UV meters are temperature stabilised to 25 ^{o}C and the exposures are recorded every five minutes. The spectral response of the meters is similar to that of the erythemal action spectrum (17). The angular response of the detectors is described by the manufacturer as within 5% from the ideal cosine response. The cosine error of the meter is reduced for the larger solar zenith angle (SZA) by calibrating in winter and summer against the scanning UV spectroradiometer described below, which has a very low cosine error for the larger SZA. The erythemal UV exposures, UV_{ery}, were calculated using the following equation:

$$UV_{ery}(SED) = T\int_{280}^{400} S(\lambda)A(\lambda)d\lambda \qquad (1)$$

where A(λ) is the erythemal action spectrum (17), S(λ) is the mean solar spectral irradiance over the 5 minutes and T is the exposure period (5 minutes). The exposures measured with the meter and the spectroradiometer were compared for the solar zenith angles encountered between morning and noon. The spectroradiometer (model DTM300, Bentham Instruments, Reading, UK) is based on a double grating monochromator, a UV sensitive detector and amplifier with software variable gain provided by a programmable high voltage power supply. The interior of the spectroradiometer enclosure is temperature stabilised to 23.0 ± 0.5^{o}C, using a Peltier heater/cooler unit. The input optics of the spectroradiometer are provided by a PTFE (polytetrafluoro ethylene) diffuser and connected by an optical fibre to the input slit of the monochromator. The spectroradiometer is scheduled to start scanning at dawn, from 280 to 400 nm in increments of 0.5 nm, and thereafter every 5 minutes till dusk. This spectroradiometer is calibrated twice yearly to a 150 W quartz tungsten halogen (QTH) calibration lamp calibrated to the National Physical Laboratory, UK standard and wavelength calibrated against the UV spectral lines of a mercury lamp.

The diffuse erythemal UV meter was specifically set up to measure the diffuse erythemal radiation by way of utilizing a shadow band to block the sun as it traverses across the sky from east to west throughout the day. The correction associated with the shadow-band of the diffuse UV radiometer has been measured at approximately 10% with the appropriate correction applied to all of the necessary data.

Model shade structure

The physical dimensions of a common public shade structure described in previous research (16) were used to build a half-size scale model at the University of Southern Queensland. The results from this model are applicable to the full size shade structure shown in Figure 1. Broadband erythemal UV and UVA measurements were conducted beneath the full-size shade structure and also beneath the scale model to validate the scale model. The UV irradiances were measured with a hand held Robertson-Berger (RB) meter (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) fitted with a UVA detector and an erythemal weighted UV detector. Differences between the erythemal UV and UVA irradiances for the model and full-size shade structures were found to be less than 4%. Details of the scale model shade structure are as follows:

- The scale model is of hexagonal shape with sides measuring approximately 1.10 m wide, 1.05 m high at the eaves, and approximately 1.50 m high at the apex. The overhang of the roof is roughly 0.28 m.

Personal dosimetry

Polysulphone dosimeters were employed to measure the erythemal UV exposure to specific anatomical facial sites. Polysulphone dosimeters were placed at sixteen different facial sites on a manikin head form in order to simulate a human head. There was negligible difference in the measured albedo (using the RB meter) between the base and head form. These facial sites have been employed based on similar sites selected in previous research to quantify the erythemal UV facial exposures (18,19). The use of manikin headforms has been previously employed in earlier research to quantify the UV exposures in different environments (for example 2,19,20). For each set of measurements, two head forms with polysulphone dosimeters attached, and affixed to rotating bases (rotating at approximately 2 revolutions per minute) were used. The height of the headforms above the ground was approximately 0.85 m. One headform in an upright position was placed in the centre of the model shade structure and one headform was positioned at least five metres from the shade structure in the full sun. The manikin headforms were then exposed from 9:00 a.m. to 12:00 noon. A series of measurements were conducted in summer and winter to account for the variation in exposure levels, SZA and atmospheric conditions experienced during the different seasons. The exposure ratios, ER, were calculated according to the following equation:

$$ER = \frac{UV_S}{UV_{FS}} \times 100\% \qquad (2)$$

where UV_S is the erythemal UV in the shade for a specific anatomical facial site and UV_{FS} is the full sun erythemal UV on a horizontal plane.

Calculation of seasonal erythemal UV in the shade

A numerical model was utilized to incorporate measurements of the ambient erythemal UV exposure in full sun and the ratio of the UV radiation to a specific anatomical site to the ambient UV on a horizontal plane. This research considers the UV exposures during a southern hemisphere winter (June to August) and summer (December to February). The erythemal UV exposure, UV_{ery}, to anatomical site, S, per day for winter and summer is calculated by using the following:

$$UV_{ery} = \sum_{h=0}^{23} AE(h) ER_S \qquad (3)$$

where AE(*h*) is the ambient erythemal UV in full sun on a horizontal plane for hour, h and ER_S is the exposure ratio for site S. This is valuable as it can provide an indication of the cumulative exposures received to any anatomical site when this specific type of shade environment is being utilized. The exposure a spectator watching a day-long cricket match during summer is one possible scenario.

RESULTS AND DISCUSSION

Global and diffuse exposures

The average global and diffuse erythemal UV exposures in the open on a horizontal plane for winter (82 days of data) and summer (97 days of data) are provided in Figure 2. The exposures are given in units of SED (standard erythemal dose) (21) with one SED equal to 100 Jm^{-2}. Differences between diffuse and global exposures are more pronounced for the lower SZA seen predominantly in the middle of the day during summer. For noon measurements during winter, average global and diffuse UV exposures were 0.37±0.05 SED/5 min and 0.22±0.05 SED/5 min, respectively. Noon measurements during summer were more than double the winter levels with average global and diffuse UV of 0.80±0.20 SED/5 min and 0.53±0.05 SED/5 min, respectively. The effect of cloud can be seen with the deviation from the bell-shaped curve. Cumulative daily global and diffuse erythemal UV exposures for winter were 22±3.8 SED and 14±3.0 SED, respectively. Cumulative daily exposures for summer were 55±13.6 SED and 42±3.1 SED for global and diffuse erythemal UV respectively.

Personal anatomical exposures

Anatomical exposures are shown in Tables 1 for winter and summer for an exposure period from 9:00 am to 12:00 noon. Maximum full sun erythemal UV exposures during winter were 7.50±0.74 SED and 5.08±1.10 SED to the top of the head and bridge of the nose respectively. The sites that received the highest erythemal UV exposures in shade were the neck and the lips with 0.60±0.16 SED and 0.54±0.06 SED respectively. The lowest exposure in the shade was observed for the top of the head with 0.10±0.01 SED.

For summer, maximum full sun erythemal UV exposures were to the top of the head and bridge of the nose with 26.12±2.22 SED and 9.24±1.40 SED respectively. The sites that received the highest erythemal UV exposures in shade were the chin and the neck with 2.14±0.04 SED and 1.98±0.10 SED respectively. The lowest exposure in the shade was observed for the top of the head with 0.12±0.01 SED.

Exposure Ratios

The exposure ratios, UV_{ER}, to each anatomical site are provided in Figure 3. These UV_{ER} values also provide information on the protection factor provided by the shade for each anatomical site. Compared to full sun erythemal UV exposures, the shade provided by the shade structures reduced the exposures to the top of the head by approximately 99% and 99.5% for winter and summer respectively. Whereas, exposure to the neck was reduced by 92% for winter and summer respectively. The largest variation in exposure ratios between the seasons was for the chin with a 4% increase in exposure ratio from winter to summer.

Shade Scenario

Calculated cumulative daily erythemal UV exposures to specific anatomical sites under the shade are provided in Figure 4. Calculated daily personal erythemal UV exposures in the shade during winter ranged from 0.3 SED per day for the top of the head to 1.8 SED per day for the chin. In comparison, erythemal UV exposures in the shade during summer ranged from 0.3 SED per day for the top of the head to 4.6 SED per day for the chin. These values give an indication of the possible daily erythemal UV dose that a person might receive to each anatomical site if the shade provided by the shade structure was utilized for an extended period of time during winter and summer. For example, a spectator watching twelve one day cricket matches during summer may receive a cumulative erythemal UV exposure of over 54 SED while in the shade. Whereas, the equivalent amount of time spent in the shade during winter would result in a cumulative erythemal UV exposure of just over 21 SED.

CONCLUSIONS

The distribution of the personal solar erythemal UV exposure beneath a very common public shade structure was assessed for the seasons of winter and summer. During winter at a sub-tropical latitude in south east Queensland, full sun UV radiation can reach levels of approximately a third or more of that registered in the middle of the day during summer. Cumulative exposure calculations were made with the assumption that no protective strategies were used apart from the shade structure itself. The results showed that the top of the head received the lowest UV dose while almost all vertical surfaces (like the chin) received much higher doses. Moreover, seasonal changes can cause significant increases in exposure. This research provides important information on the possible cumulative solar erythemal UV exposures that persons using similar shade structures may receive.

Infrequent over exposure and cumulative exposure to UV radiation are both important risk factors in the development of skin cancer. As a result, minimizing the exposure to solar UV radiation is essential. This is of great importance during childhood, as a reduction in childhood exposures may have significant implications for cancer rates later in life. Therefore, having appropriate shade environments at childhood centres and pre-schools is vital in limiting the levels of detrimental solar UV radiation children are exposed to.

Shade is a very important part in minimising UV exposure. However, shade alone does not always provide enough protection from damaging UV radiation. Additional sun protection strategies such as the use of hats, sunglasses, clothing and sunscreen should still be employed, even if seeking shade for an extended period of time during the winter months

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Table

Table 1. Average anatomical facial exposures from 9am to noon beneath the model shade structure for winter and summer. Standard deviations are provided in the parentheses.

	Winter (SED)		Summer (SED)	
Site	Shade	Full Sun	Shade	Full Sun
top of head	0.10 (0.01)	7.50 (0.74)	0.12 (0.01)	26.12 (2.22)
forehead	0.40 (0.12)	4.58 (0.56)	1.18 (0.01)	7.23 (1.12)
bridge of nose	0.46 (0.12)	5.08 (1.10)	1.42 (0.02)	9.24 (1.40)
lips	0.54 (0.06)	2.56 (0.12)	1.76 (0.01)	6.42 (0.96)
chin	0.34 (0.08)	1.04 (0.17)	2.14 (0.04)	5.00 (0.78)
cheeks	0.32 (0.08)	2.26 (0.10)	1.50 (0.01)	6.00 (0.24)
ears	0.42 (0.16)	2.52 (0.78)	1.36 (0.08)	5.18 (0.78)
neck	0.60 (0.16)	3.90 (0.50)	1.98 (0.10)	7.00 (2.00)
back of head	0.42 (0.10)	3.00 (0.50)	1.56 (0.02)	7.06 (0.94)
eyes	0.36 (0.06)	2.24 (0.20)	1.24 (0.08)	5.16 (0.52)

Figures

Figure 1. The commonly employed shade structure used in this research.

Figure 2. Average diffuse and global erythemal UV irradiances for winter (a) and summer (b). The error bars indicate, for one data point as an example, the combined standard deviations of the data for the three months used for each season.

Figure 3. Exposure ratios for each of the anatomical body sites for the seasons of winter and summer. The error bars indicate the standard deviation of the data.

Figure 4. Calculated cumulative daily erythemal UV exposures in the shade for each anatomical site for winter and summer.

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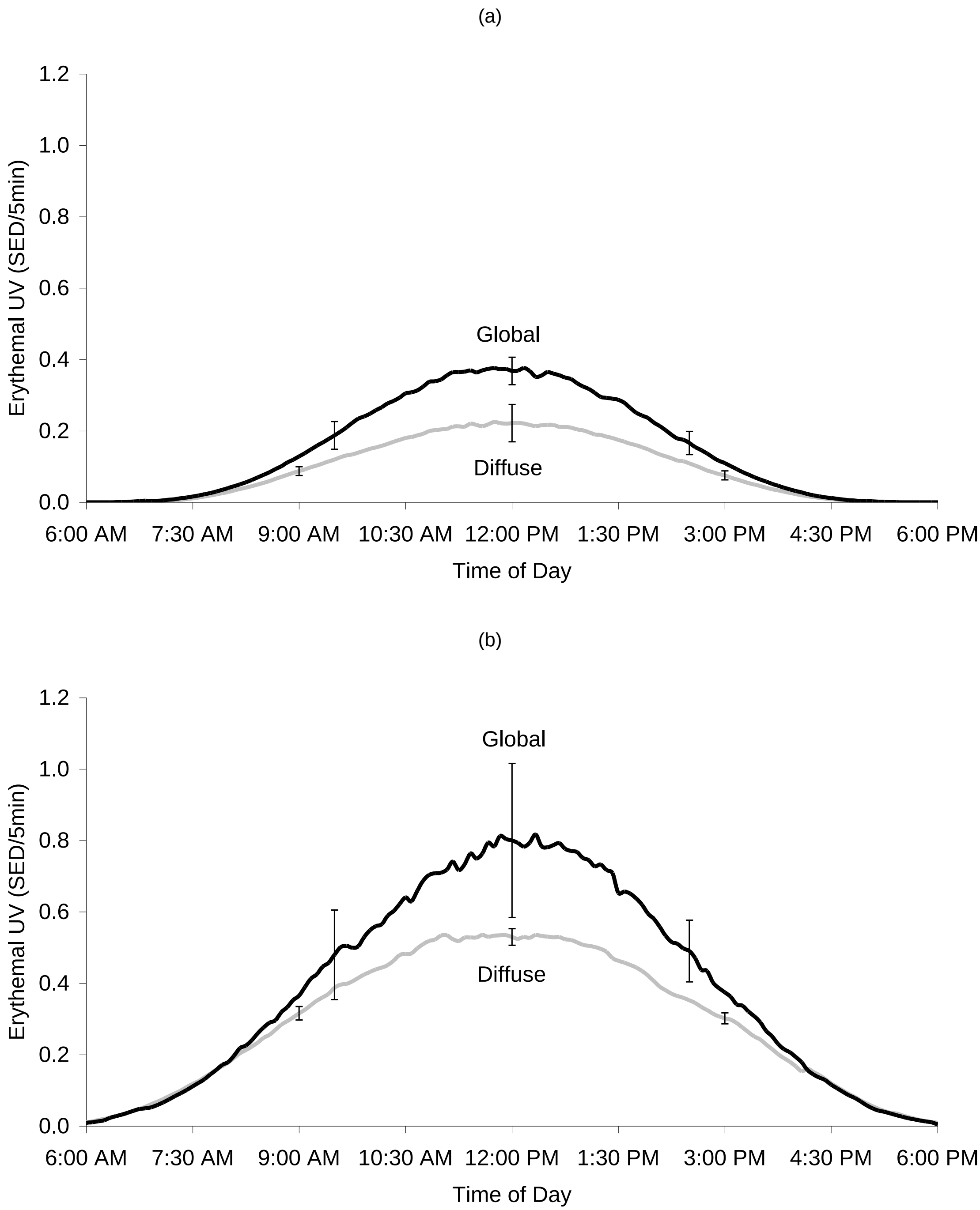

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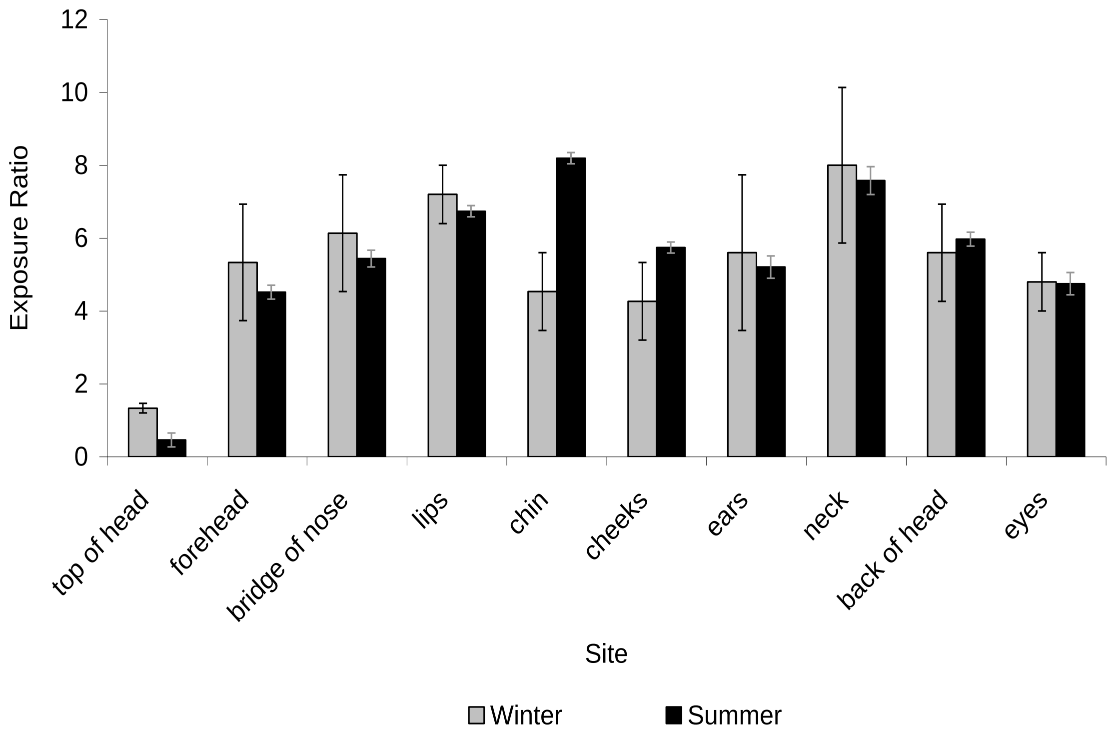

Figure 3. Exposure ratios for each of the anatomical body sites for the seasons of winter and summer. The error bars indicate the standard deviation of the data.

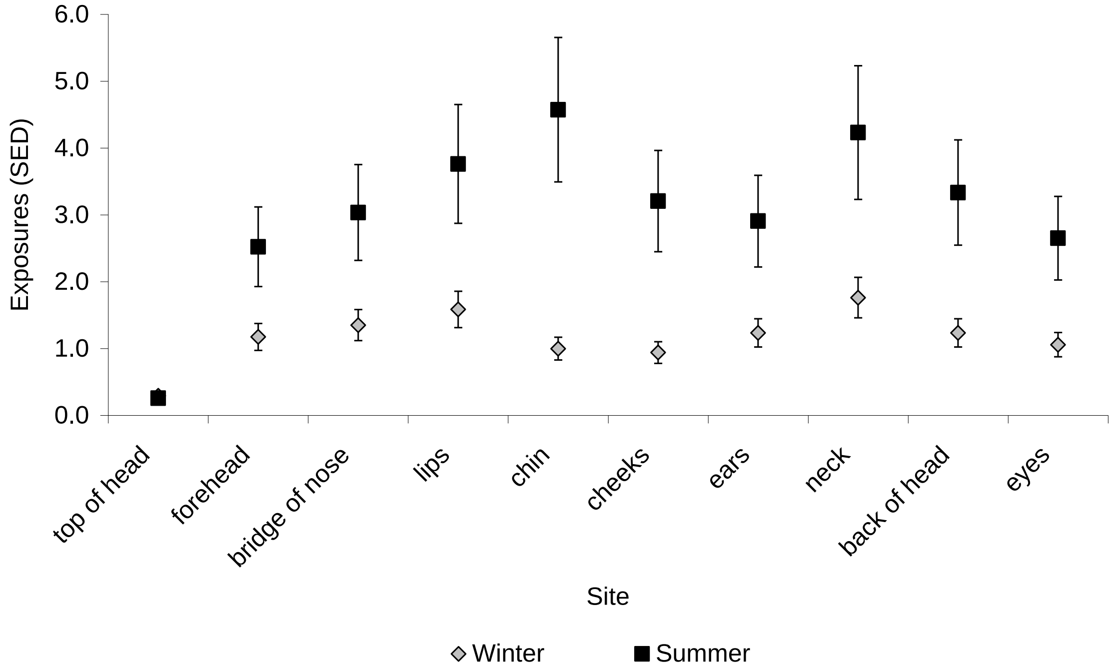

Figure 4. Calculated cumulative daily erythemal UV exposures in the shade for each anatomical site for winter and summer.