REDUCTION IN THE PERSONAL ANNUAL SOLAR ERYTHEMAL ULTRAVIOLET EXPOSURE PROVIDED BY AUSTRALIAN GUM TREES

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Abstract:

The fraction and the distribution of the personal daily solar erythemal UV exposure were assessed for the shade provided by Australian gum trees in each of the four seasons to allow evaluation of the reduction in the personal UV exposure in tree shade over a year. The personal annual erythemal UV exposures in the tree shade ranged from 2,510 SED (Standard Erythema Dose) for the vertical part of the ear to 8,016 SED for the vertex of the head compared to 14,834 SED to a horizontal plane in full sun. The erythemal UV seasonal exposures for 15 minute intervals on a horizontal plane in full sun in winter are comparable to the UV exposure to the vertex of the head in shade in autumn and spring. The UV exposure in the tree shade for summer, is approximately 20% less than the full sun exposure in autumn. The reduced personal annual erythemal UV exposures due to the tree shade provided reductions by a factor of 2 to 3 and 4 to 6 in the contribution to the risk of basal cell carcinomas and squamous cell carcinomas respectively compared to not employing the protection of the tree shade.

INTRODUCTION

Prevention of skin cancer, premature skin ageing and sun related disorders of the eyes requires the minimisation of ultraviolet (UV) radiation exposure. The usage of tree shade during outdoor activities forms an essential component of a UV exposure limitation strategy and is promoted by Health authorities. The diffuse radiation comprises a significant proportion of the UV radiation exposure to humans. This is particularly so in tree shade where the diffuse component of the erythemal UV radiation on a horizontal plane was measured to comprise approximately 60% of the total UV in the Australian summer (December to February)[(1)]. The terrestrial UV is comprised of the UVA (315-400 nm) and UVB (280-315 nm) wavebands. Both the wavebands are responsible for skin damage, however, the UVB waveband has the higher relative effectiveness, by a factor of the order of 1000 or more, for producing certain skin cancers, DNA damage and eye damage[(2-5)]. The spectrum of the reflected and scattered UV is altered from that of direct sunlight. Specifically, there is an increased proportion of the shorter UVB wavelengths. One of the reasons for this is the greater scattering by molecules and particles at the shorter wavelengths. This scattering is called Rayleigh scattering and increases with the fourth power of the wavelength towards the shorter wavelengths and results in five to ten fold more UVB being scattered compared to visible radiation[(6)]. This combined with the higher effectiveness of the UVB for producing carcinogenic, eye and DNA damage highlights the dangers of the diffuse UV for humans.

Diffuse UV radiation can enter the shaded area either directly or by scattering through the leaf canopy. Research has modelled and measured the UV exposures on horizontal surfaces shaded by tree canopies[7,8]. In addition, research is required on the personal UV exposure to specific human anatomical sites in order to investigate the protection provided to humans by tree shade.

Previous research has measured the UV exposure on a horizontal plane for tree shade in summer[6] and the personal UV exposure in tree shade at different times of the year[9] and over a summer[10]. These studies investigated the UV exposure at certain points or times of the year. These results may not be valid for an entire year as the solar zenith angle changes along with the relative proportions of the direct and diffuse radiation. The annual UV exposure to infants and small children has been estimated[11]. Wong et al.[12] have calculated the annual UV exposure to the facial region with and without a hat. To the authors' knowledge, no previous research has measured the UV exposure in each of the four seasons to human anatomical sites while sheltering in tree shade and evaluated the respective annual UV exposure. This research evaluates the cumulative annual erythemal UV exposure while sheltering in tree shade of single Australian gum trees and determines the associated reduction in the contribution to the risk of non-melanoma skin cancer (NMSC).

MATERIALS AND METHODS

Shade Provision

The definition of shade is taken in this paper as the visible shade boundary as cast by the shadow of the tree trunk and canopy. No measurements were undertaken if no visible shade boundary was obvious as a result of cloudy conditions. The trees employed in this research have been described elsewhere[10]. Briefly, the trees were in the grounds of the University of Southern Queensland, Toowoomba (27.5 ^{o}S), Australia and they were mainly a range of Australian gum trees (Eucalyptus sp.). The trees were selected so that the visible shade boundary of each tree was independent of the shadow of neighbouring trees or structures. For the trees, the width of the canopies was larger than 2 m, the height above the ground to the top of the canopy ranged between 9 and 23 m and the height above the ground to the start of the tree canopy ranged between 1 and 10 m. The tree canopy transmission in the visible waveband ranged from 0.45 to 0.94 (on a scale of 0 to 1). The angle of sky obscured by the tree canopy from a point on the ground directly below the centre of the canopy ranged from approximately 30 to 146 ^{o}.

Annual UV Exposures

The annual UV exposures were calculated for the case that the subject is both outdoors and in an upright stance in the shelter of the tree shade during all of the daylight hours. This may not be totally realistic as it does not take into account the activity of the subject outside of the shade, however, the aim of the research was to investigate the influence of the tree shade alone. Similarly, no account was taken of the usage of clothing, hat and sunscreen. The measurements started on 1 December, 1998 and the annual erythemal exposures to each anatomical site, UV_{ery}, were calculated using a previously developed model(13,14) as follows:

$$UV_{ery} = \sum_{m}\sum_{d}[AE].[SER] \qquad \mathbf{SED} \qquad (1)$$

where AE is the ambient erythemal UV exposure on a horizontal plane, SER is the shade exposure ratio for each site as defined below, the erythemal UV is the UV spectrum weighted with the erythemal action spectrum(2) and the subscript ery relates to erythema. The summation is over the number of days, d, in each month of the year, m. The exposures are provided in units of SED (Standard Erythema Dose)(15) with one

SED equal to 100 J m^{-2}. The solar erythemal exposure is applicable to the actinic exposure for eye damage[4] as the actinic action spectrum is similar to the action spectrum for erythema over the solar UV range of 295 to 400 nm.

The ambient erythemal UV exposures on a horizontal plane were measured with a UV meter (model 501, Solar Light Co., Philadelphia, USA). This meter was mounted on a horizontal unshaded plane on a building roof at the University of Southern Queensland and recorded the exposures for every 15 minute interval of the day. The meter was calibrated in each of the four seasons, using the solar spectrum between 9:00 EST and noon, as the source against a calibrated spectroradiometer[16].

Shade Exposure Ratios

The shade exposure ratio for an anatomical site was defined as the exposure to that site while in the tree shade divided by the exposure on a horizontal plane in full sun. The exposure to each site was measured as described elsewhere using polysulphone dosemeters deployed on upright manikins on a rotating platform[10]. This was to simulate humans in a predominantly upright stance. The manikins were placed in the approximate centre of the tree shade and they were moved throughout the day to remain in the centre of the shade. The error associated with the measurement of UV exposures with calibrated polysulphone dosemeters is of the order of 10%[17].

Simultaneously, two dosemeters were deployed in full sunlight on a horizontal plane in the vicinity of the trees to measure the ambient UV exposure to allow calculation of the shade exposure ratios. The ambient exposures measured by these dosemeters were employed rather than the exposures recorded by the UV meter in the previous section as the dosemeters were able to be placed in the field in the same environment as the trees. The ratios are expected to change with the time of day and year. This was taken into account by measuring the SER in each of the four seasons of the year and by deploying the manikins between 09:00 EST and 15:00 EST to determine the average SER over the period that provides the majority of the daily solar UV exposure.

The research in this paper has made no attempt to measure the shade exposure ratios for set atmospheric conditions and tree parameters. Alternatively, in this research the shade exposure ratios were measured for a range of 17, 13, 20 and 15 trees in summer, autumn, winter and spring for any of the atmospheric conditions encountered during each season. The same set of trees was used in each season. The reason for this was that over a given season, the public will shelter from the sun in a range of trees for a range of atmospheric conditions. The only exception was that no measurements were undertaken if there was so much cloud that the boundary of the tree shade was not visible. Consequently, the average of the shade exposure ratios for each anatomical site has been calculated for each season and employed in Equation (1). Each of the four shade exposure ratios have been employed for the three months in each respective season. The alternative technique of using the average SER values for the centre month of the season and using the least squares method to fit a quadratic to allow interpolation of the SER's for the intermediate months was tested. The differences between the resultant annual exposures to each site was 2% or less.

The shade exposure ratio for the respective season and for each anatomical site was employed in Equation (1) to provide the UV_{ery}^{S} for each day. These were summed over the days of each month to provide the monthly erythemal UV exposures. These monthly exposures were summed to provide the seasonal and annual erythemal UV exposures.

Reduction in NMSC Risk

Epidemiological research has established the relationship between the annual erythemal UV exposure and the annual contribution to the risk of NMSC, R, for a group of subjects with a given genetic susceptibility as follows[13]:

$$\boldsymbol{R} \quad \boldsymbol{\alpha} \quad (\boldsymbol{UV_{ery}})^{\boldsymbol{BAF}} (\boldsymbol{age})^{\boldsymbol{\alpha}} \tag{2}$$

where BAF is the biological amplification factor with estimates of 1.4 ± 0.4 for basal cell carcinoma (BCC) and 2.5 ± 0.7 for squamous cell carcinoma (SCC)[18]. For a given age, the ratio of the annual contribution to the risk of NMSC for a subject in full sun and receiving an annual erythemal UV exposure of $\boldsymbol{UV_{ery}^{o}}$ compared to sheltering continuously in tree shade and receiving an annual erythemal exposure of UV_{ery}^{S} was calculated as follows:

$$\left(\frac{UV_{ery}^{o}}{UV_{ery}^{S}}\right)^{BAF} \tag{3}$$

Lifestyle Scenarios

The effect on the annual erythemal UV exposure for the scenario of sheltering in the tree shade during the weekends and indoors for the remainder of the week was investigated. This is to simulate the case of subjects who are indoors during the week, for example, indoor workers and who shelter in the tree shade while outdoors on the weekend, for example, as spectators at their children’s weekend sporting events. The respective shade exposure ratio for the appropriate season was employed. The second scenario of subjects who are indoors except for the period of noon to 13:00 EST and who are outdoors and shelter in the tree shade during this period was considered. This case was to simulate indoor workers who are outdoors during their lunch hour.

RESULTS

Monthly Exposures

The shade exposure ratios averaged over the trees are shown in Figure 1 for summer and winter. The error bars represent the standard error in the mean. For the facial sites, the vertical sites of the cheek, chin and the vertical part of the ear are the best protected. Although for some months, the shade exposure ratios for the two seasons are within the error bars of one another, the exposure ratios in summer are generally lower than those in winter. The range in winter is 0.21 to 0.59 compared to the range in summer of 0.16 to 0.49. This is a result of the higher proportion of diffuse UV radiation in winter due to the higher solar zenith angles. Although, there may be overcast days in summer with a high proportion of diffuse UV radiation, averaged over the respective seasons, the shade exposure ratio is generally higher in winter. This has been found to be the case in full sun by other research(19), however, the research in this paper has quantified this for tree shade.

The monthly exposures on a horizontal plane in full sun and in the tree shade to the vertex of the head, right shoulder, chin, right cheek and front of the right shin are provided in Figure 2. The variation in terms of SED over the months of the year is not as high in the shade as it is in the full sun. For example, for a horizontal plane in full sun, the difference in the UV_{ery} exposure for January and July is 1,501 SED, whereas, the variation in the shade for the horizontal plane of the vertex of the head is 689

SED. For a site on an approximately vertical plane, such as the chin the same variation is 281 SED.

The average daily UV_{ery} exposures for the month of January and July are provided in Table 1. The error in these values due to the standard error in the mean of the exposure ratios in Figure 1 is of the order of 10% or less. In the tree shade the average daily UV_{ery}^{S} exposures range from 10 to 32 SED/day in January for the right ear and vertex of the head respectively and 4 to 10 SED/day in July for the same two sites. In the sun, the ratio of the January to July daily exposure is 3.8 compared to the same ratio in the shade of 3.0 ± 0.1 when averaged over the sites.

Tree Shade Annual UV

The erythemal UV seasonal totals for each 15 minute interval of the day for the vertex of the head in tree shade and on a horizontal plane in full sun (autumn and winter) and for the cheek in tree shade are shown in Figure 3. Any deviation from the bell shaped curve is due to the influence of changing atmospheric conditions. The annual UV_{ery} exposures in the tree shade to each of the sites along with the annual exposure in the sun on a horizontal plane are shown in the final column of Table 1. The personal annual erythemal UV exposures in the tree shade ranged from 2,510 to 8,016 SED.

Reduction in NMSC Risk

The ratio of the annual contribution to the risk of SCC and BCC for full sun exposure compared to sheltering continuously in tree shade is shown in Table 2 for the vertex of the head, forehead and cheek. The ratios range from 4 to 6 for SCC and 2 to 3 for BCC.

Lifestyle Scenarios

The annual UV_{ery}^{S} in the tree shade for the scenario of an indoor worker who shelters in the tree shade on the weekends as a sports event's spectator and an indoor worker who is outside in the tree shade during a lunch break between noon and 13:00 EST are provided in Table 3. The case of the indoor workers who spend the lunch hour outdoors in the tree shade provides a UV exposure that is approximately half of that for the case of the subjects who spend the whole weekend in the tree shade with the remainder of the week indoors. It is worthwhile to note that despite the reduction in the tree shade provided, some of the sites for scenario 2, namely, the vertex of the head, shoulder and nose receive an exposure in excess of 2 SED per day during the 1 hour period.

DISCUSSION

The fraction and the distribution of the personal daily solar erythemal UV exposure was assessed for the shade provided by Australian gum trees, in each of the four seasons, to allow evaluation of the reduction in the personal cumulative erythemal UV exposure in tree shade over a year in south east Queensland, Australia. To the authors' knowledge, this is the first experimental evaluation of the annual erythemal UV exposure in tree shade. The calculations were made under the assumptions that: no UV protective strategies apart from sheltering in the tree shade were employed; during all hours outside, the subject was upright in the tree shade; the subject was sheltering in the shade of a single tree. The latter assumption is because the UV protection provided by the shade of a single tree is different to that provided by a full forest canopy where the amount of visible blue sky is different. The UV exposure in tree shade is dependent on the solid angle of blue sky at the point of exposure.

Consequently, the results in this paper are relevant only to single tree canopies. However, it is still relevant for playgrounds and sporting fields where generally there are isolated trees rather than a group of trees forming a canopy. The research results in this paper may be different for other species of trees with different leaf canopies. Although, the exposure ratios in this research may vary at other latitudes due to different atmospheric pathlengths, the research in this paper is relevant to sub-tropical latitudes in both northern and southern hemispheres. No attempt was made to model the influence of different cloud and atmospheric conditions. Instead, the integration of the UV exposure provided by the dosemeters took into account variations throughout the day and the average exposure ratios were calculated from the measurements over 13 to 20 days in each season. This was done to take into account the variations in the atmospheric conditions and the different trees within the one species of tree that a subject will use for shelter from the sun over a season of the year.

Comparison of the annual exposure to the horizontal plane of the vertex of the head in the shade shows that it is 1.9 times higher than the annual ambient erythemal UV exposure on a horizontal plane in sun at Durham, UK (55 ^{o}N). This emphasises the high solar UV exposures in south-east Queensland. The UV_{ery} seasonal totals for the 15 minute intervals on a horizontal plane in sun in the winter are comparable to the exposure to the vertex of the head in shade in autumn and spring. Similarly, the UV_{ery}^{S} exposure in the tree shade for summer, is about 20% less than the full sun exposure in autumn. Nevertheless, the reduction in the personal annual erythemal UV exposures provided reductions by a factor of 2 to 3 and 4 to 6 in the contribution to the risk of BCC and SCC respectively. The error in the measurement of the UV exposures is of the order of 10%. Propagation of this error in the risk assessment calculation provides an error of the order of 28% and 50% for the BCC and SCC calculations respectively due to the errors in the UV exposure measurements.

The cooler temperatures in the tree shade raise the possibility of staying outdoors for a longer time due to reduced thermal discomfort or alternatively, the possibility of not taking any other UV prevention strategies or possibly both. This becomes a serious consequence when it is coupled with the relatively high UV exposures all year round in excess of 2 SED per day for the tree shade as measured in this research. These average daily exposures are in excess of the limit for occupational UV exposure in Australia[(20)].

Acknowledgments: *This research was partially funded by Queensland Department of Health. Two of the authors (RL and DT) were employed through the funding. The authors also acknowledge Meegan Wilson who was employed by the funding during the summer.*

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Table 1 - The average daily UV_{ery} for January and July and the annual* UV_{ery} in full sun on a horizontal plane and to the anatomical sites in the tree shade.

Site	Average January daily UV_{ery} (SED)	Average July daily UV_{ery} (SED)	Annual* UV_{ery} (SED)
Sun - Horizontal Plane	66	17	14,834
Shade - Vertex of Head	32	10	8,016
Shade - Right Ear	10	4	2,510
Shade - Nose	22	7	5,721
Shade - Right cheek	11	4	2,587
Shade - Chin	13	4	3,203
Shade - Forehead	17	6	4,440
Shade - Right Shoulder	27	9	6,950
Shade - Right Shin Front	17	5	3,742
Shade - Right Shin Back	12	4	2,943

*This is the cumulative erythemal UV over a year.

Table 2 – Ratio of the annual contribution to the risk of SCC and BCC for full sun exposure compared to sheltering continuously in tree shade.

Site	SCC	BCC
Vertex of Head	5	2
Forehead	6	3
Cheek	4	2

Table 3 - The annual UV_{ery} in the tree shade for the scenario of an indoor worker who shelters in the tree shade on the weekends as a sports event's spectator (scenario 1) and an indoor worker who is outside in the tree shade during a lunch break between noon and 13:00 EST (scenario 2).

	Annual Erythemal UV Exposure (SED)	
Site	Scenario 1	Scenario 2
Shade - Vertex of Head	2,305	1,370
Shade - Right Ear	722	431
Shade - Nose	1,644	979
Shade - Right cheek	745	442
Shade - Chin	922	547
Shade - Forehead	1,275	762
Shade - Right Shoulder	1,998	1,189
Shade - Right Shin Front	1,078	637
Shade - Right Shin Back	846	504

FIGURE CAPTIONS

Figure 1 - The shade exposure ratios averaged for the trees in summer and winter.

Figure 2 - The UV_{ery} exposures for each month in (a) full sun and to the vertex of the head in shade (b) to the right shoulder and chin in shade and (c) to the right shin front and right cheek in shade.

Figure 3 - The UV_{ery} seasonal totals for the 15 minute intervals for (a) the vertex of the head in tree shade and on a horizontal plane in full sun (autumn and winter) (b) the cheek in tree shade.

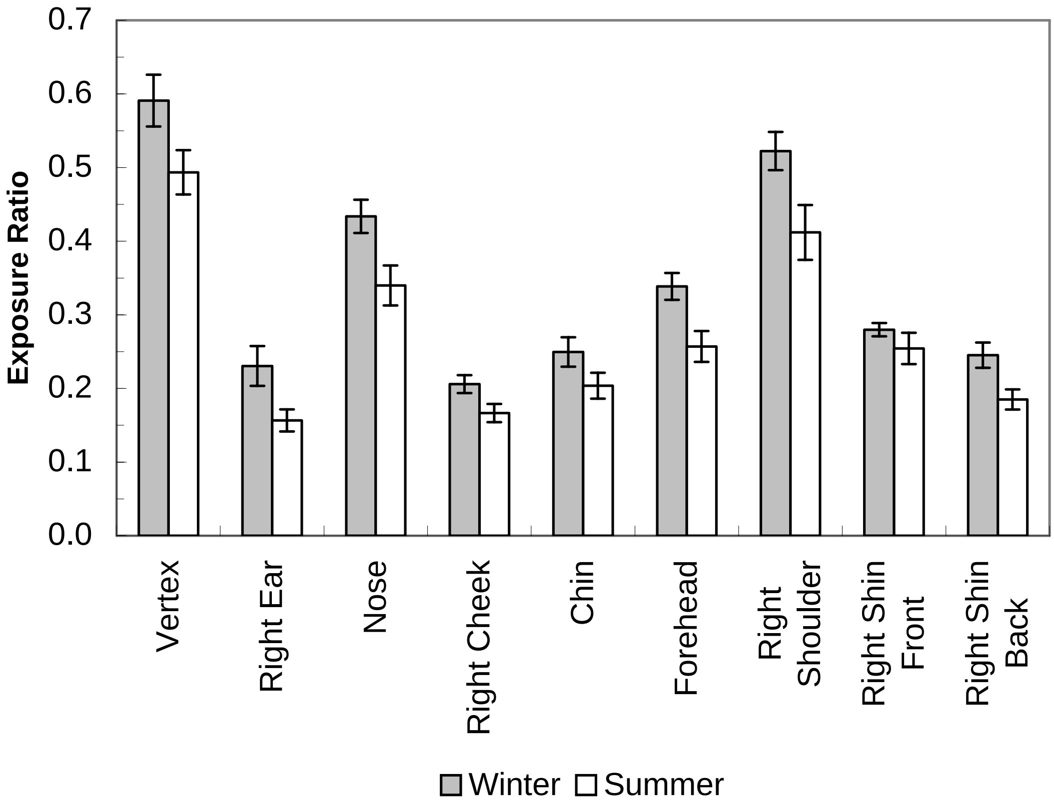
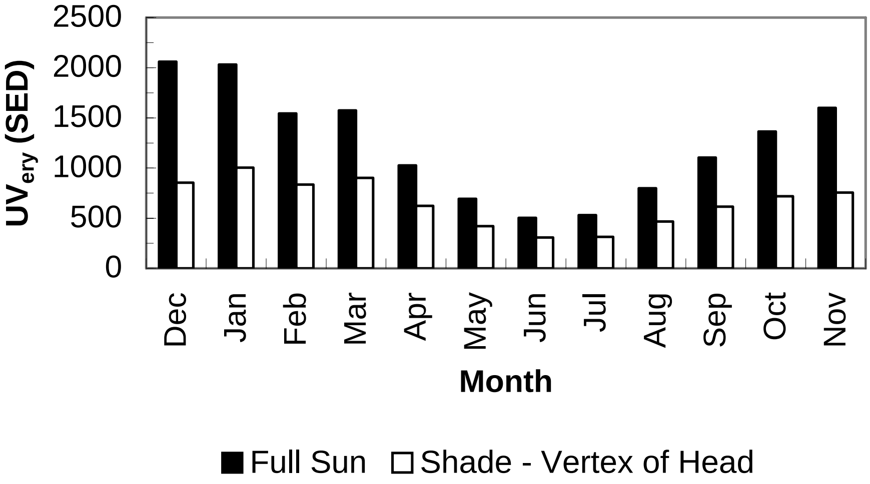


Figure 1 - The shade exposure ratios averaged for the trees in summer and winter.

(a)



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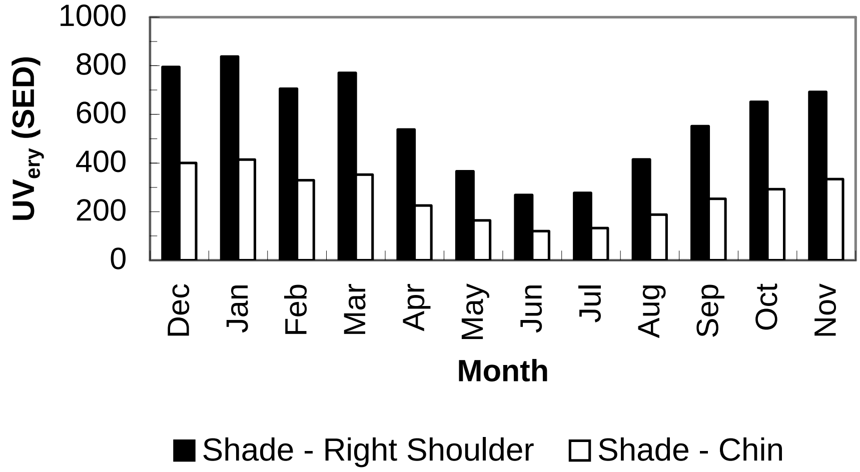

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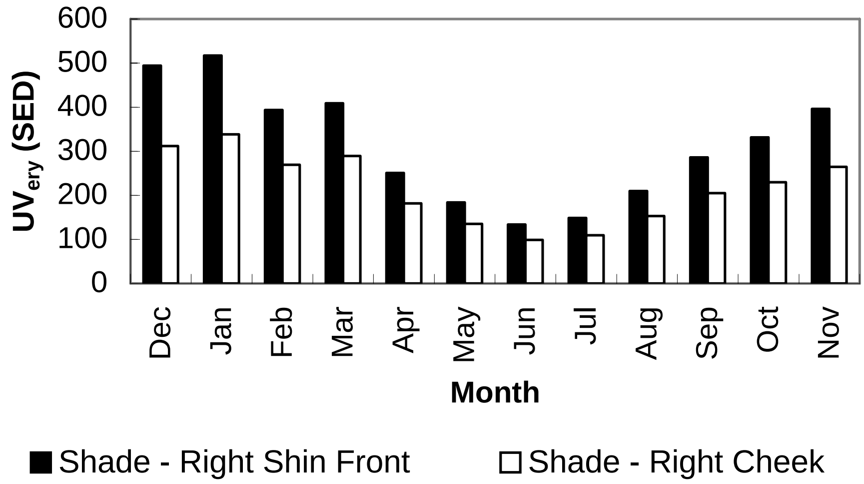
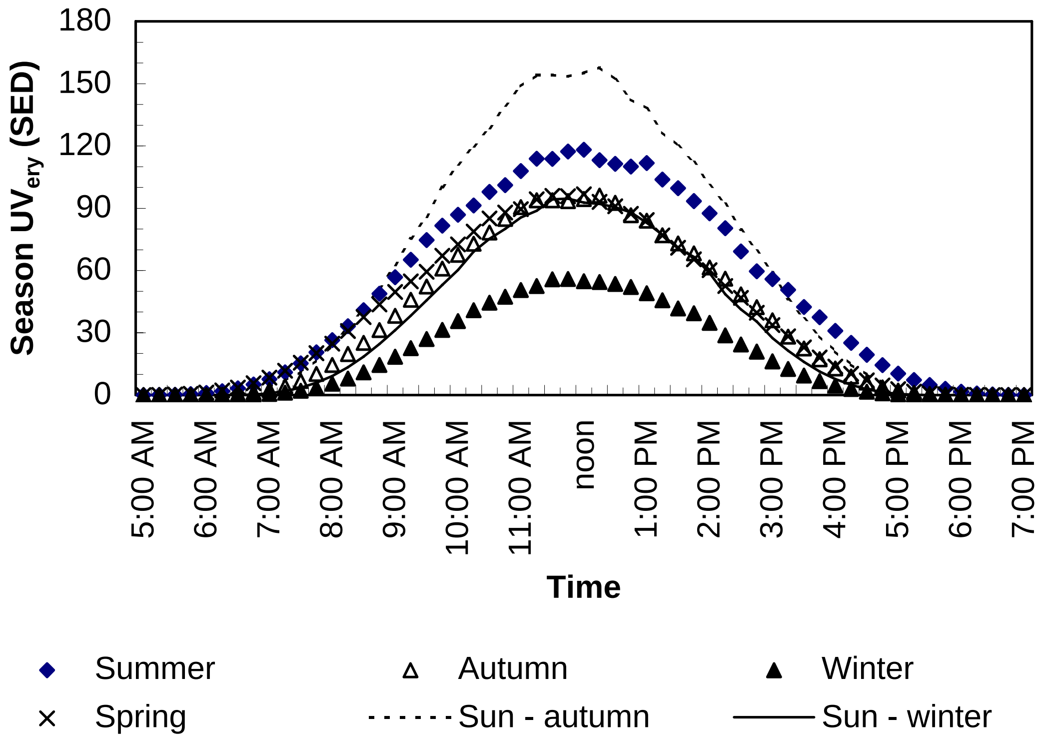


Figure 2 – The UV_{ery} exposures for each month in (a) full sun and to the vertex of the head in shade (b) to the right shoulder and chin in shade and (c) to the right shin front and right cheek in shade.

(a)



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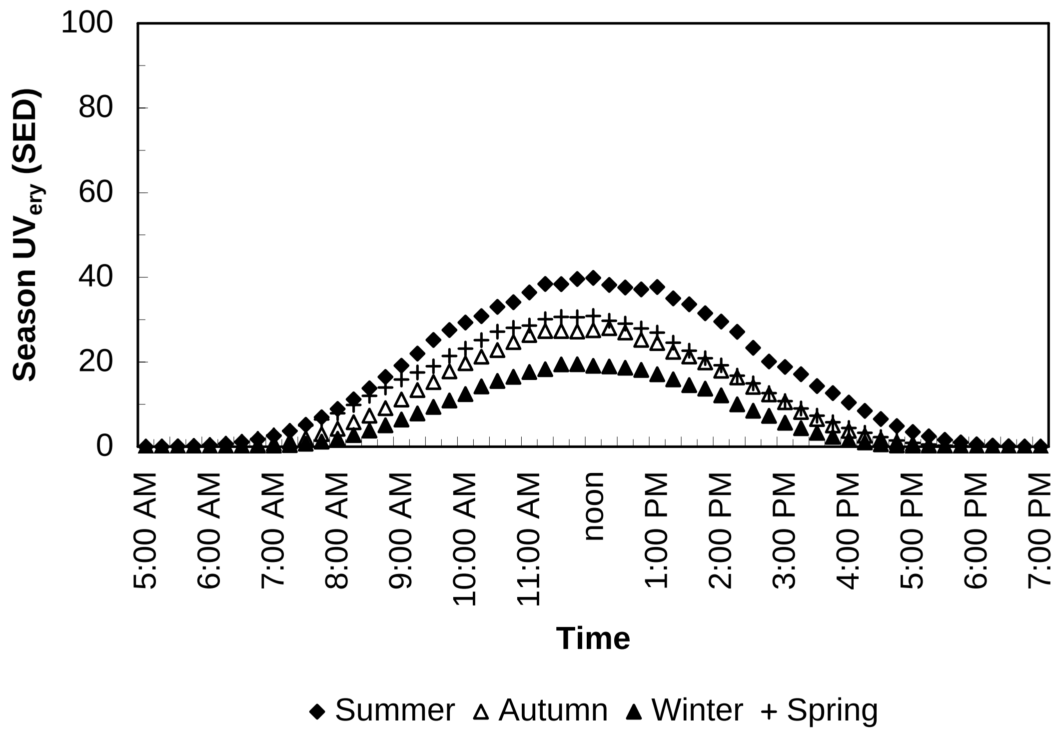

Figure 3 - The UV$_{ery}$ seasonal totals for the 15 minute intervals for (a) the vertex of the head in tree shade and on a horizontal plane in full sun (autumn and winter) (b) the cheek in tree shade.