

Utilising shade to optimize UV exposure for vitamin D

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Abstract. Numerous studies have stated that humans need to utilise full sun radiation, at certain times of the day, to assist the body in synthesising the required levels of vitamin D₃. The time needed to be spent in the full sun depends on a number of factors, for example, age, skin type, latitude, solar zenith angle. Current Australian guidelines suggest exposure to approximately 1/6 to 1/3 of a minimum erythemal dose (MED), depending on age, would be appropriate to provide adequate vitamin D₃ levels. The aim of the study was to determine the exposure times to diffuse solar UV to receive exposures of 1/6 and 1/3 MED for a changing solar zenith angle in order to assess the possible role that diffuse UV (scattered radiation) may play in vitamin D₃ effective UV exposures (UV_{D₃}). Diffuse and global erythemal UV measurements were conducted at five minute intervals over a twelve month period for a solar zenith angle range of 4° to 80° at a latitude of 27.6° S. For a diffuse UV exposure of 1/3 MED, solar zenith angles smaller than approximately 50° can be utilised for exposure times of less than 10 min. Spectral measurements showed that, for a solar zenith angle of 40°, the UVA (315–400 nm) in the diffuse component of the solar UV is reduced by approximately 62% compared to the UVA in the global UV, whereas UV_{D₃} wavelengths are only reduced by approximately 43%. At certain latitudes, diffuse UV under shade may play an important role in providing the human body with adequate levels of UV_{D₃} (290–315 nm) radiation without experiencing the high levels of UVA observed in full sun.

1 Introduction

The health effects of solar UV radiation vary significantly, from initiating the synthesis of vitamin D₃ to the severe degradation of the human body. Excessive solar UV radiation exposure led to the premature deaths of approximately 60 000 people in the year 2000 (Lucas et al., 2006). It is well known that exposure to small amounts of UV radiation are beneficial for the human body and important in the production of vitamin D₃, whereas excessive exposure to sunlight is known to cause skin cancer, immune suppression, DNA damage, erythema and sun-related eye disorders (Baron et al., 2003; Glerup et al., 2000; Terenetskaya, 2000; Sliney, 2004; Setlow et al., 1993). Approximately 90–95% of our vitamin D₃ requirement comes from exposure to the sun (Holick, 2004; Holick, 1998). The synthesis of pre-vitamin D₃ is initiated through exposure of human skin to terrestrial UV radiation from 290 to 315 nm. The longer wavelength UV radiation (greater than 315 nm) plays no part in the synthesis of pre-vitamin D₃ in humans. Although, over exposure to UV wavelengths is known to cause damage, vitamin D₃ synthesis occurs at doses far below those needed for erythema to arise (Webb, 1993). Small amounts of vitamin D₃ can also be obtained from some foods, for example oily fish and eggs or by fortifying foods with vitamin D₃. It has been shown that the vitamin D₃ from these sources cannot provide sufficient vitamin D₃ for the elderly (Mosekilde, 2005). Vitamin D₃ can also be obtained through vitamin tablets; however the simplest way to obtain vitamin D₃ is from moderate exposure to sunlight (Holick, 2004). Furthermore, this is also the cheapest way without the cost burden of vitamin tablets.

Current Australian guidelines suggest exposure to approximately 1/6 to 1/3 of a MED (minimum erythemal dose), depending on age, would be appropriate to provide adequate vitamin D₃ levels (Samanek et al., 2006; CDHAA, 2004). Older people require more frequent exposures as vitamin D₃ production rates are about 1/5 as high for the elderly as for



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the young (Holick et al., 1989). Also, people with highly pigmented skin would require exposures 3–4 times greater than those necessary for fair skinned people (Pathak et al., 1999). Recent research suggests that the optimal serum vitamin D₃ level for bone health and protection against other diseases is between 800 and 2000 IU per day (Aloia and Li-Ng, 2007; Lappe et al., 2007; Vieth et al., 2007; Dawson-Hughes et al., 2005); with 1000 IU equivalent to exposing 15% of the human body to approximately 1/3 MED (PS, 2006). A position statement was recently approved by the Working Group of the Australian and New Zealand Bone and Mineral Society, Endocrine Society, Osteoporosis Australia, Australian College of Dermatologists and the Cancer Council Australia recommending five minutes solar UV exposure either side of the peak UV periods on most days of the week in summer and approximately 2–3 h solar UV exposure over a week in winter (PS, 2006). This position statement is still behind emerging scientific findings (e.g. Giovannucci et al., 2006; Grant et al., 2007; Gorham et al., 2007; Garland et al., 2007). Nevertheless, it is still the most up to date statement that has been distributed to the public. The position statement is also a generalized report as sun exposure varies significantly with latitude and atmospheric conditions.

Solar UV radiation is incident on the earth's surface in two distinct components, direct and diffuse. The direct component is straight forward to minimise by simply blocking its path, whereas the diffuse component is incident from all directions and is difficult to minimise. Atmospheric scattering which is influenced by factors such as solar zenith angle (SZA), clouds and atmospheric constituents plays a major role in determining the proportions of UVB (280–315 nm) and UVA (315–400 nm) in diffuse UV, with greater scattering occurring at the shorter UVB wavelengths than at the longer wavelength UVA. Turnbull et al. (2005) found that UVA was reduced by as much as 65% when utilising a shade umbrella, whereas UVB exposures were only reduced by approximately 48%. Therefore, at certain SZA, the diffuse UV may provide adequate levels of the effective wavelengths needed for vitamin D₃ production (UV_{D₃}), without producing erythema. In comparison, mutagenic and carcinogenic effects on human skin have been shown to be caused by exposure to UVA radiation (Agar et al., 2004; Moan et al., 1999; Garland et al., 2003). Therefore, reducing personal exposures to UVA radiation while still receiving sufficient amounts of the UV_{D₃} wavelengths required to produce recommended vitamin D₃ levels is essential.

The importance of this research is that it provides a basis for public health campaigns aimed at reducing the incidence of hypovitaminosis D and its attendant disorders, as well as reducing over exposure to harmful solar UV radiation. In the light of the considerable body of evidence regarding the harm done by excessive UV exposure and the public awareness of skin cancer, any new public health program would need to avoid confusing the public with seemingly opposing messages. Utilizing diffuse solar UV radiation to obtain

beneficial amounts of UV, while at the same time minimizing personal overexposure to UVA radiation may prove to be absolutely necessary for an improvement in public health. Studies have shown that shade structures are important as a UV minimisation strategy; however, shade settings may also play an important role in providing exposures to the human body with adequate levels of UV radiation for vitamin D₃ production without experiencing the higher levels of UVA experienced in full sun. The lengths of exposure to solar UV at noon in major Australian cities to produce exposures of 1/3 and 1/6 MED has previously been reported (Samanek et al., 2006). Shade as a protective device has been discussed numerous times before (e.g. Turnbull and Parisi, 2006) and it is not the aim of this paper. This current paper is about the exposures that humans may receive when utilising solar UV for vitamin D₃ synthesis and the possible methods to optimise this radiation. The author's are unaware of any similar research or attempts to show how solar UV exposures can be optimised so humans can receive adequate vitamin D₃ levels as well as reducing their total UV exposure.

2 Materials and methods

2.1 Integrated automated cloud and spectral UV measurement system

An integrated automated cloud and spectral UV measurement system was employed at a Southern Hemisphere site at Toowoomba, Australia (27.6° S, 151.9° E, 693 m above sea level) for automatically measuring every five minutes both the cloud fraction and the UV spectrum. The system was located on the roof of a building with relatively unobstructed views and the surrounding topography does not provide any significant obstruction to the field of view of the instruments.

The cloud detection system is a Total Sky Imager (TSI) (model TSI-440, Yankee Environmental Systems, MA, USA) with approximately 160° field of view of the sky. The TSI consists of a CCD camera suspended over a hemispherical reflective dome that points upwards on a horizontal plane. For each image, digital analysis provides the fraction of cloud cover as a number between 0 and 1 where 1 represents total cloud cover. The uncertainty in the determination of the amount of cloud has been reported as ±10% at least 95% of the time (Sabburg and Long, 2004).

The spectral UV measurement system is located within three metres of the cloud detection system and is housed in an environmentally sealed box with a fibre optic connecting the diffuser to the input slit of the monochromator through a hole with a seal around the fibre to protect the equipment inside the box from the environment. The system is based on a double monochromator system model (DTM300, Bentham Instruments, Reading, UK) with the gratings having 2400 grooves/mm. The input and output slit widths on the monochromator of 0.37 mm have been selected to provide a

bandwidth of 0.5 nm. The spectral UV data was recorded from 280 to 400 nm in 0.5 nm increments. The input optics are provided by a diffuser (model D6) with the manufacturer determined error associated with the cosine response as less than $\pm 0.8\%$ for a SZA up to 70° and $\pm 3.3\%$ for an SZA of 80° . The system is scheduled to scan every five minutes from 05:00 EST (Eastern Standard Time) to 17:00 EST and the start of the initialisation of a spectral scan is one minute before the TSI obtains an image of the sky. This allows the spectral scan to start at approximately the same time that the TSI takes the sky image. Wavelength and irradiance calibration of the spectral UV system was undertaken by employing the 365 nm mercury spectral line and a 150 Watt quartz halogen lamp with calibration traceable to the National Physical Laboratory, UK standard.

2.2 Diffuse and global erythemal UV

Two erythemal UV meters (UV-Biometer Model 501, Solar Light Co., Philadelphia, PA. USA) were employed to monitor the diffuse and global erythemal UV (UV_{ery}). The diffuse UV_{ery} meter is a global UV_{ery} meter that has been specifically set up to measure the diffuse erythemal radiation. It utilizes a shadow band, which is aligned east-west, to block the sun during the day. The shadow band is 0.076 m wide and the distance from the shadow band to the top of the diffuse UV_{ery} meter varies from 0.25 m to 0.27 m as it is moved with the seasons. The shadow band blocks out part of the sky view and the amount blocked has been measured at approximately 10%. A correction has been applied to all of the data to account for this. The diffuse and global UV_{ery} meters were set up to record data every five minutes. The meters are temperature stabilized to 25°C and calibrated twice a year during clear sky conditions against the scanning spectroradiometer. The daily atmospheric column of ozone as obtained from the TOMS (Total Ozone Mapping Spectrometer) ranged from 243.5 to 337.0 DU and the SZA ranged from 4° to 80° over the twelve month measurement period from January to December 2003.

3 Results

3.1 Diffuse and global erythemal UV

An example of diffuse and global UV spectra is shown in Fig. 1a for a cloud free period on 17 August 2005 at 11:55 EST for an SZA of 40° . This illustrates the variation in the relative proportions of the different wavelengths when comparing diffuse UV to global UV. For Fig. 1a, the diffuse spectral irradiance summed over the UVA waveband was 16.8 W/m^2 compared to 44.5 W/m^2 for the global UVA. Similarly, the diffuse UVB was 0.63 W/m^2 compared to 1.12 W/m^2 for global UVB. For this specific date and time, the UVA was reduced by approximately 62% compared to the global UVA, whereas the diffuse UVB was only reduced

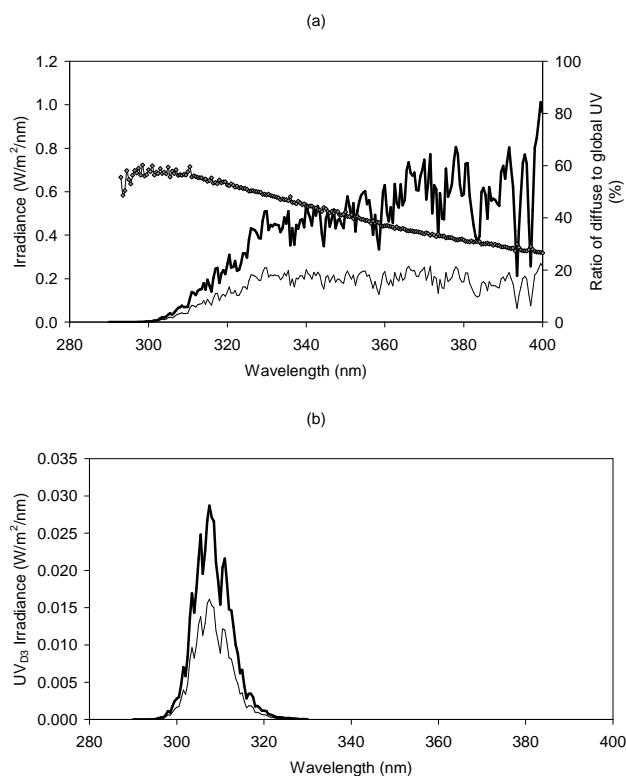


Fig. 1. Diffuse (light line) and global (heavy line) spectral UV irradiances taken on 17 August 2005 at approximately 11:00 EST and the spectral ratio of diffuse to global UV (a); and global and diffuse spectral irradiances from Fig. 1a weighted with the pre-vitamin D₃ action spectrum (CIE, 2006) (b).

by approximately 44%. The ratio of the diffuse to global UV plotted on the right hand axis of Fig. 1b gives an indication of the change in ratio when comparing global and diffuse UV wavelengths.

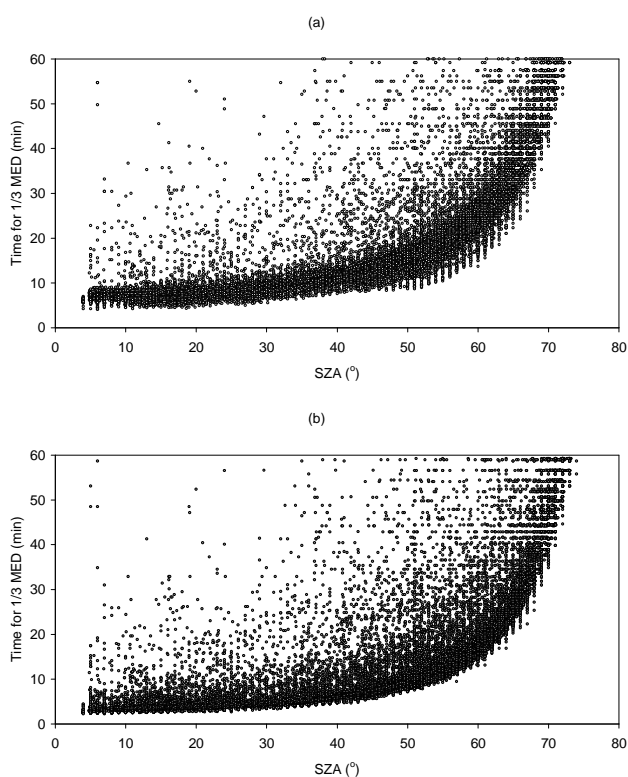
Figure 1b provides the global and diffuse solar UV spectra (from Fig. 1a) weighted with the pre-vitamin D (CIE, 2006) action spectrum. Pre-vitamin D₃ exposure was reduced by 43% whereas UVA exposure was reduced by 64%. These spectral measurements were obtained using the spectral measurement system described earlier.

3.2 Exposure times for 1/3 MED

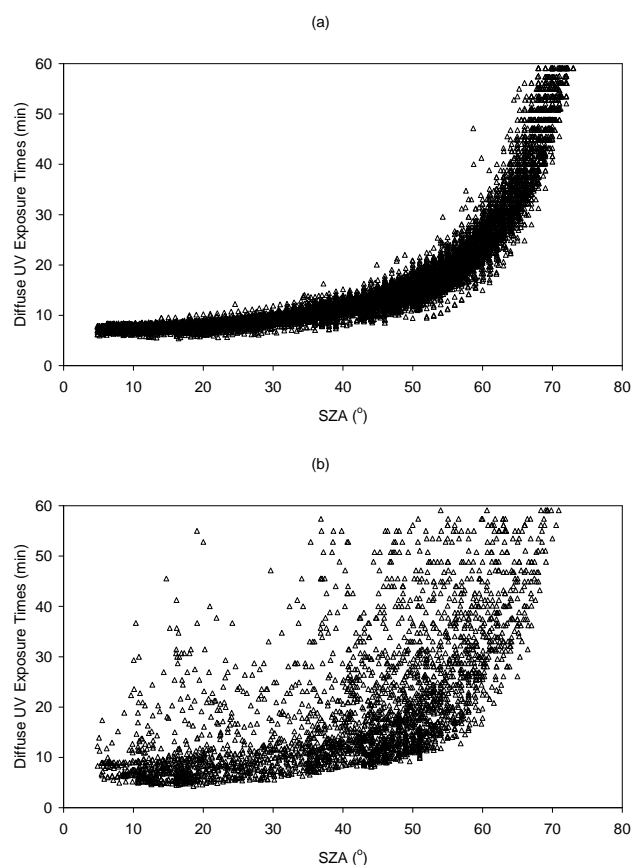
The times required for an exposure of 1/3 MED on a horizontal plane for SZA greater than 4° for the atmospheric and cloud conditions during 2003 are shown in Fig. 3a for diffuse and Fig. 3b for global UV_{ery} . Over 25 000 data points are provided in each figure for diffuse and global UV_{ery} for all SZA, sky and atmospheric conditions encountered over this period. The average times for an exposure equivalent to 1/3 MED for vitamin D₃ and erythema are shown in Table 1 for diffuse and global UV. For a SZA of 5° , the average time needed to receive an exposure of 1/3 MED due to erythemal

Table 1. Average times for an exposure equivalent to 1/3 MED for vitamin D₃ and erythral effective UV radiation.

| | Global UVD ₃ | Diffuse UVD ₃ | Global UV _{ery} | Diffuse UV _{ery} |
|-----|-------------------------|--------------------------|--------------------------|---------------------------|
| SAZ | (min) | (min) | (min) | (min) |
| 5° | 2.2 (0.8) | 3.2 (0.5) | 4.4 (2.5) | 6.8 (2.8) |
| 15° | 2.5 (3.4) | 3.9 (3.1) | 5.1 (5.9) | 7.7 (5.2) |
| 25° | 2.8 (1.8) | 4.5 (2.6) | 6.0 (4.5) | 8.7 (4.0) |
| 35° | 3.5 (2.0) | 5.2 (2.5) | 7.1 (4.2) | 10.2 (4.3) |
| 45° | 5.7 (3.8) | 7.1 (3.1) | 10.8 (6.6) | 13.7 (5.4) |
| 55° | 10.1 (5.9) | 13.2 (7.7) | 19.9 (16.5) | 24.2 (16.3) |
| 65° | 27.5 (19.0) | 27.2 (17.2) | 42.0 (30.8) | 43.6 (25.1) |
| 75° | 103.3 (63.5) | 97.7 (47.7) | 110.3 (56.3) | 111.6 (49.3) |

**Fig. 2.** The times required for an exposure of 1/3 MED due to diffuse UV_{ery} (a) and global UV_{ery} (b) as a function of SAZ for all sky conditions during 2003.

UV was 4.4 and 6.8 min for global and diffuse respectively. Whereas, the average time needed to receive an equivalent exposure of 1/3 MED for vitamin D₃ production was 2.2 and 3.2 min for global and diffuse respectively. These times are based on exposing 15% of the human body to UV radiation. Increasing the exposed body surface will subsequently decrease the time needed for vitamin D₃ production (e.g. exposing three times more body surface will reduce the exposure times presented in this research by a factor of three).

**Fig. 3.** Times for exposure to 1/3 MED of diffuse UV for cloud cover of 0 to 80% (a) and 85 to 100% (b).

However, the time for 1/3 MED of erythral effective UV will remain the same.

As shown in Fig. 3a and b, this data has been broken down into separate cloud levels of 0 to 80% and 85 to 100%, respectively. This was undertaken to illustrate that 0 to 80% of cloud cover has a lesser effect on the diffuse UV compared to 85 to 100% of cloud.

The times required for an exposure of 1/3 MED due to the diffuse and global UV_{ery} on a horizontal plane expressed as a percentage of occurrence for 2003 are shown in Fig. 4. For diffuse UV_{ery} , the maximum incidence for 1/3 MED was in the range of 5 to 10 min with an occurrence of 34.9%, followed by 29.5% for 10 to 15 min, and 17.8% for 15 to 20 min. For global UV_{ery} , the maximum incidence of the times for 1/3 MED was in the range of 5 to 10 min with an occurrence of 32.9%, followed by 26.7% for less than or equal to 5 min, and 17.9% for 10 to 15 min.

4 Discussion

Studies on the levels of UV observed in the shade of different shade environments have shown that the relative proportions of UVA and UVB in the shade are significantly different to those in full sun (Turnbull et al., 2005; Turnbull and Parisi, 2003; Turnbull et al., 2003; Parisi et al., 2001). The relative proportions of the UVA in shade to those in full sun are decreased compared to the relative proportions of the UVB in shade to those in full sun. At certain latitudes and SZA, unprotected exposure for short periods to the UV under shade structures may be the best course of action as it will contribute more toward vitamin D₃ production than toward erythema compared to exposing the body to full sun UV due to the reduced relative component of the UVA in the shade.

The average time for an exposure of 1/3 MED due to diffuse UV_{ery} was 6.8 min for a SZA of 5°. Whereas, the average time needed to receive an equivalent exposure of 1/3 MED for vitamin D₃ production was only 3.2 min. These times are longer for larger SZA and for overcast conditions. For an exposure of 1/3 MED, SZA smaller than approximately 50° can be utilised for exposure times of less than 10 min. For SZA between 4° to 50°, 94% of the data shows that an exposure of 1/3 MED requires less than 20 min of exposure to diffuse UV. Although the measurements are at one latitude, the data was collected for the SZA range of 4° to 80°. This will allow the results to be applicable at latitudes that experience these SZA.

The values provided in this paper are for pale skin and for a sky view that is not blocked, apart from the blocking of the solar disc. However, research is currently being conducted beneath various shade environments and initial results show that shade environments of at least 50% sky view exhibit excellent correlation with the values shown in Fig. 2a. For example, at approximately 18° SZA the average time for 1/3 MED from diffuse UV_{ery} on a horizontal plane is approximately 7.5 min. Initial results for the same SZA show that the times for 1/3 MED in the shade of a shade umbrella and on the southern side of a building were approximately 7 min and 9 min respectively. For larger structures the amount of sky view will be reduced due to the structural components of the shade structure, causing the exposure times required for the respective exposures due to the diffuse UV_{ery} to be

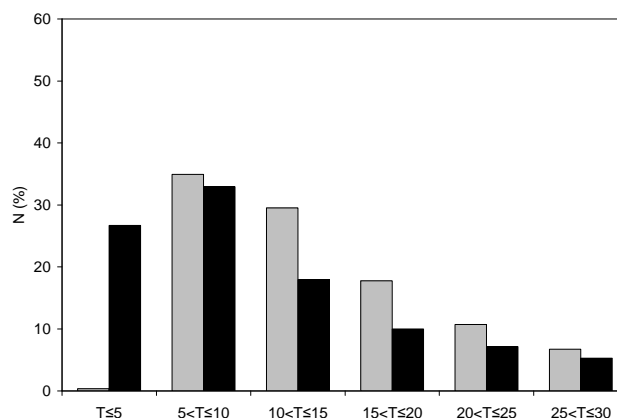


Fig. 4. The percentage of instances when the time required for an exposure of 1/3 MED due to diffuse (grey bar) and global (black bar) UV_{ery} falls within a certain time range (provided in units of minutes).

slightly longer. Nevertheless, the findings in this paper may have significant ramifications for future public health policy regarding sun exposure, which is currently being debated in many countries (Diffey, 2006; Gillie, 2006). Also, the findings of this research may prove useful to those that work from 9 a.m. to 5 p.m., where solar UV exposure at noon or during a lunch break may be the only option for the necessary UV exposures to initiate the synthesis of vitamin D₃. Therefore, advice to stay out of the sun in the middle of the day, which is best for vitamin D₃ synthesis in the skin, can be adjusted to advocate the possible use of appropriate shade environments. However, in the shade there is the potential danger due to the filtering of the infrared waveband, which may cause prolonged exposures.

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