# Anatomical distribution of ultraviolet solar radiation

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**Exposure to high levels of erythemal ultraviolet radiation (EUVR) is known to have adverse effects on human health. Certain parts of the human body are more susceptible to high EUVR exposure than others. The EUVR exposure of 26 anatomical sites on a mannequin was quantified on clear-sky and overcast days using polysulphone film. On clear-sky days, horizontal anatomical sites received the highest EUVR exposure. Facial exposure ranged between 19% and 56% of the vertex of the head. The hand and arm also received relatively high EUVR exposure (>50% of the vertex). Vertical surfaces averaged 38% of the vertex. These percentages compared closely with those of similar studies conducted elsewhere. EUVR exposure received across all anatomical sites on an overcast day was approximately 30% of that received on a clear-sky day.**

## Introduction

Exposure to high levels of EUVR is known to have adverse consequences for human health including erythema, non-melanoma skin cancer (NMSC) and malignant melanoma skin cancer (MMSC).[1] Childhood and adolescence has been identified as a period of potential increased risk.[2,3] South Africa has one of the highest skin cancer rates in the world.[4] To reduce the incidence of skin cancer using primary prevention, the nature of human EUVR exposure needs to be understood.[5]

EUVR exposure for some anatomical sites has been measured using personal EUVR dosimeters on mannequins and humans in the U.K.[6,7] and Australia.[8–10] Few studies of anatomical EUVR exposure have been conducted in South Africa. Guy *et al.*[11] quantified the daily EUVR exposure of 30 children and adolescents in Durban over a 2-week period during late summer. The mean and median daily exposure for all ages over the study period were 2.1 SED and 1.2 SED (1 standard erythemal dose = 100 J $m^{-2}$, minimum exposure required to induce erythema), respectively.

Quantification of the anatomical distribution of EUVR is important to understand the aetiology of UVR-related diseases and to guide the design of sun protection programmes.[5] Anatomical EUVR exposure depends on factors such as angle of body site towards the sun and degree of sun protection, for instance, clothing and sunscreen.

## Methods

Ambient EUVR was measured continuously by a Yankee Environmental Systems broadband UVB pyranometer. Details of the instrument's operation are given elsewhere.[12,13]

An upright rotating mannequin was used to estimate the EUVR exposure incident upon 26 anatomical sites. The mannequin stood on a grassed, non-shaded location for five clear-sky and two overcast days for two and four hours around local noon, respectively. The period was shorter on clear-sky days to avoid saturation of the polysulphone film badges (PSFBs). A half-hour break between morning and afternoon periods was allowed to facilitate changing of the PSFBs. The orientation of the mannequin was standardized to face true north for the first 15 minutes of each UVR exposure period and was rotated 90° in a clockwise direction every 15 minutes, completing a 360° revolution in one hour.

PSFBs have been used in other studies to measure erythemal UVR.[8,10,14] PSFB absorbance ($A$) changes when exposed to EUVR and by measuring this change in $A$ at 330 nm ($A_{330}$) the degree of degradation is quantified as EUVR exposure.

Calibration of the PSFBs ($y$) was done against broadband UVR measurements ($x$) made by the YES UVB pyranometer, where $y = 5069x^2 + 505x$. Pre- and post-exposure $A_{330}$ measurements were undertaken using a Varian DMS 300 UV/visible spectrophotometer.

A PSFB control was placed 1.5 m away from the mannequin on a horizontal, non-shaded surface. Each control PSFB was exposed for the same period as the anatomical PSFBs. The EUVR exposure of each anatomical site was then calculated as a percentage of the ambient EUVR for concurrent periods of exposure using either the PSFB control measurement or that obtained from the YES UVB pyranometer.

## Results and discussion

### Ambient erythemal UVR

Diurnal variations in ambient EUVR recorded by the YES UVB pyranometer are shown in Fig. 1. The sinusoidal envelope of the clear-sky group is striking, with a single midday maximum of ~80 mW $m^{-2}$. On overcast days, EUVR fluctuated and was mostly lower than on clear-sky days. However, the maximum value recorded on 15 August is indicative of the difficulties that arise when quantifying the effect of overcast skies on ambient UVR, since even when cloud cover measures 8 octas, maximum values may be high owing to the influence of scattering, reflection and occasional periods when the sun breaks through the cloud.

### Clear-sky conditions

Mean EUVR exposure values for each anatomical site over the five days are displayed in Table 1. As expected, the vertex received the greatest EUVR exposure (273 J $m^{-2}$), since it was the most horizontal site and was never in the shade.

Indeed, it received more UVR than that of the control (246 J $m^2$), which was surprising. The most likely explanation is a slightly longer exposure time of the former, as the PSFBs were removed manually and hence not simultaneously, although reflection of UVR from surfaces surrounding the vertex cannot be eliminated. The shoulders, chest, arms, hands and face also experienced high EUVR exposure (>150 J$m^{-2}$). The high values recorded for the chest and hand were likely caused by the protruding nature of the chest and the horizontal orientation of the hand. The EUVR exposure of the hands generally provides a good approximation of EUVR exposure to the face and lapel.[28] However, in this study, the EUVR exposure of the hand (183 J $m^{-2}$) exceeded that of the face (range 84–153 J $m^{-2}$) by 33–142%. The lower back, trunk and back of the arms experienced relatively low EUVR exposure (<100 J $m^{-2}$). EUVR exposure of the legs was fairly consistent, ranging between 101 and 133 J $m^{-2}$.

EUVR exposure for all anatomical sites measured during the morning was similar to that recorded in the afternoon (Table 1), except for sites on the sides of the body that were affected by the changing position of the sun and the effect of rotating the

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mannequin. Solar zenith angles over the study period ranged from 60.5° to 55.0° between 11:00 and 12:00, and 53.5° to 53.0° between 12:30 and 13:30.

The vertex is used as a benchmark against which EUVR exposure of other anatomical sites are compared[6,7,15] in order to eliminate variations in absolute UVR intensity on a day-to-day and geographical basis. EUVR exposure for all anatomical sites was computed as a percentage of the vertex (Table 1). Facial exposure ranged between 19–56% of the vertex, with the forehead and nose each receiving over 55%. High EUVR exposure of facial sites corresponds to the relatively high rates of NMSC.[16,17] The front of the arms, hands and the lower limbs, also common sites of NMSC, received an average of 65–41% of the vertex. These anatomical sites tend to be frequently exposed to EUVR, particularly in warm climates where people may wear less protective clothing in summer.

Vertical surfaces received 13–76% of the vertex, with an average of 38%. Exposure on horizontal surfaces was higher, ranging between 47 and 82% of the vertex (average of 60%). A study by Diffey[16] obtained an average of 38% and 75% for vertical and horizontal sites, respectively, indicating the greater susceptibility of horizontal anatomical sites to relatively high EUVR exposure.

Table 2 compares the EUVR exposure of six anatomical sites relative to the vertex obtained for this study and three other mannequin studies.[6,7,10] Results are generally in close agreement with at least one of previous studies. The only anatomical site for which a relatively large discrepancy was noted, was the chin, as a result of its protruding nature and hence higher EUVR exposure.

Anatomical EUVR exposure expressed as a percentage of the ambient EUVR (measured by the YES pyranometer and the control PSFB) for the same periods of exposure, over the five-day period for clear-sky conditions, was calculated for certain anatomical sites. Results are presented in Table 3 together with those from a similar study conducted in England for a rotating mannequin and humans.[16] Results compare closely for the cheek and upper arm. UVR exposure for the shoulder and chest were higher than those obtained in other studies, whereas that of the lower back was considerably lower. Some of the differences between the results may be accounted for by the sedentary nature of a mannequin and changing positions of people.

## Overcast conditions

The relationship between cloud cover and EUVR is complex as clouds may serve either to enhance or to reduce EUVR irradiance, depending, in part, on the relative position of the sun, optical cloud depth, cloud height, cloud type and water droplet size distribution.[18] Uniformly overcast skies tend to

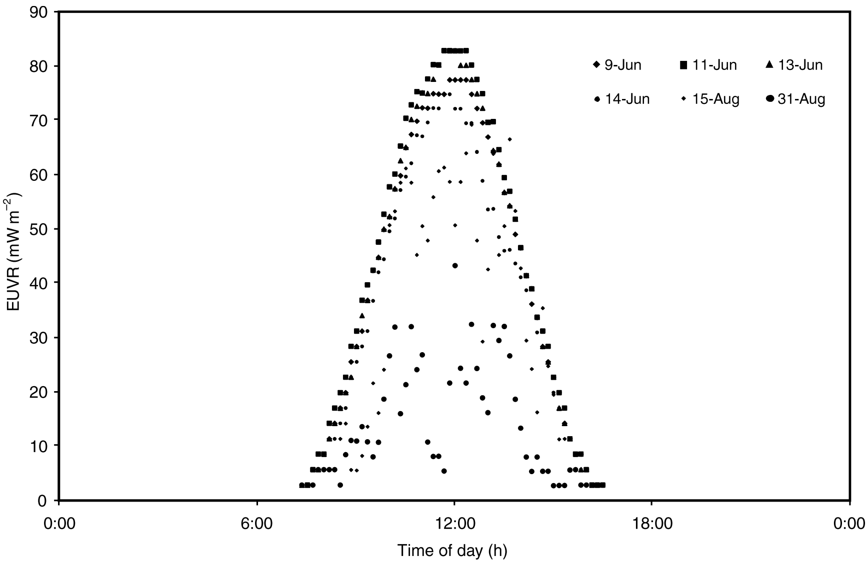


**Fig. 1**. Ambient EUVR (mW m$^{-2}$) as recorded by the YES UV pyranometer in Durban for four clear-sky days (6, 9, 11, 13, 14 June 2001) and two overcast days (15, 31 August 2001).

**Table 1**. Mean EUVR exposure (J m$^{-2}$) for 26 anatomical sites for five clear-sky days and 2 overcast days.

| Anatomical site* | Clear-sky mean total EUVR exposure (J m$^{-2}$)# | Clear-sky percentage of the vertex (%) exposure (J m$^{-2}$ | Overcast sky mean) total EUVR |
|---|---|---|---|
| Control | 246.1 | – | 122.2 |
| Vertex of the head (H) | 272.7 | 100.0 | 189.9 |
| Top l. ear (H) | 129.7 | 47.6 | 127.3 |
| Forehead (V) | 153.3 | 56.2 | 76.0 |
| L. cheek (V) | 84.3 | 30.8 | 58.4 |
| R. temple (V) | 101.0 | 37.0 | 54.6 |
| Side l. ear (V) | 52.1 | 19.0 | 57.5 |
| Bridge of nose (A) | 151.9 | 55.6 | 79.8 |
| Chin (A) | 112.9 | 41.4 | 45.7 |
| R. shoulder (H) | 222.6 | 81.6 | 152.7 |
| R. scapular (V) | 76.6 | 28.0 | 63.3 |
| Centre chest (V) | 206.4 | 75.6 | 121.8 |
| L. lapel (V) | 169.3 | 62.0 | 115.6 |
| Back r. u. arm (V) | 81.9 | 30.0 | 59.7 |
| Back r. elbow (V) | 61.7 | 22.6 | 32.3 |
| Front r. mid-forearm (A) | 186.5 | 68.3 | 118.7 |
| Front r. u. arm (A) | 167.2 | 61.3 | 82.4 |
| Front r. hand (A) | 182.5 | 66.8 | 148.6 |
| Nape of neck (V) | 74.4 | 27.2 | 40.2 |
| Centre u. back (V) | 96.8 | 35.4 | 68.5 |
| Centre l. back (V) | 36.1 | 13.2 | 19.1 |
| R. kneecap (V) | 107.5 | 39.4 | 64.2 |
| Back l. knee (V) | 133.5 | 48.9 | 84.2 |
| Front r. mid-calf (V) | 101.4 | 37.1 | 54.5 |
| Back l. mid-calf (V) | 111.2 | 40.7 | 69.9 |
| Back l. ankle (V) | 111.1 | 40.7 | 60.8 |
| Front r. foot (A) | 127.1 | 46.6 | 71.5 |

*H, horizontal site; V, vertical site; A, angular site; R/r, right; L/l, left.
#Clear-sky exposure periods were from 11:00–12:00 and 12:30–13:30. Overcast sky exposure periods were from 10:00–12:00 and 12:30–14:30. Mean total EUVR exposure includes both morning and afternoon exposure excluding 12:00–12:30.

**Table 2**. EUVR exposure expressed as a percentage of the vertex for six anatomical sites for this study and three similar studies.

| Anatomical site | Diffey *et al.*[6] | Diffey *et al.*[7] | Kimlin *et al.*[9] | This study (2001) |
|---|---|---|---|---|
| Vertex | 100 | 100 | 100 | 100 |
| Forehead | – | 58 | 43 | 56 |
| Nose | – | 66 | 57 | 55 |
| Chin | – | 34 | 12 | 41 |
| Cheek | 31 | 29 | 21 | 30 |
| Shoulder | 68 | – | 80 | 81 |
| Chest | 73 | – | – | 75 |

reduce ambient EUVR, whereas partly cloudy conditions may either reduce or enhance surface EUVR.[18] Under thick overcast cloud, ambient EUVR is ~20% of that received under clear-sky conditions.[19]

In this study, EUVR exposure was measured under overcast skies (8 octas) with no substantial clearing. However, even under these overcast conditions, EUVR fluctuated during the day (Fig. 1) as a result of variable cloud densities.

**Table 3**. Comparison between EUVR exposure as a percentage of the ambient EUVR exposure of a rotating mannequin and living subjects for a study conducted in England[16] and this study.

| Anatomical site | Living subjects[16] (% ambient EUVR) | Mannequin[16] (% ambient EUVR) | Mannequin (this study) (% ambient EUVR measured by YES pyranometer) | Mannequin (this study) (% ambient EUVR measured using PSFB) |
|---|---|---|---|---|
| Cheek1 | 5–47 | 31 | 35 | 34 |
| Shoulder | 66–70 | 75 | 85 | 90 |
| Lower sternum (chest) | 44–46 | 66 | 80 | 83 |
| Lumbar spine (lower back) | 58–71 | 47 | 15 | 14 |
| Upper arm | 59–66 | 52 | 64 | 67 |
| Dorsum of hand | 24–78 | 42 | 78 | 74 |

All anatomical EUVR exposures were less than 200 J m$^{-2}$, with the exception of the vertex and hand (Table 1). In these two cases there was little difference between clear-sky and overcast exposures, although the period over which the EUVR exposure was recorded under overcast conditions was twice as long as under clear-sky conditions. A comparison between mean EUVR exposure across all anatomical sites on clear-sky and overcast days, where exposure was normalized to a 1-hour period by taking an arithmetic average and neglecting the different exposure periods of clear versus overcast days, revealed that overcast exposure was on average 30.7% of clear-sky exposure. This confirmed that uniformly overcast skies suppress anatomical EUVR exposure.

## EUVR exposure by anatomical site for children and adolescents

The vertex, face, shoulders, arms and hands are the anatomical sites most vulnerable to high EUVR exposure. Based on results of a previous study in Durban,[11] which estimated the mean daily EUVR exposure during summer for the lapel anatomical site to be 2.1 SED, and using the relationships to the vertex (Table 2), we computed the mean daily anatomical distribution of EUVR for children and adolescents (Fig. 2).

The EUVR exposure for the vertex, shoulders, face, chest, hands and front of the legs was above 1.5 SED (150 J m$^{-2}$). All of these sites are likely to experience erythema, depending on individual skin type. The vertex and forehead received between 2.5 and 4 SED, indicating that, irrespective of skin type, these sites are at a high risk of experiencing erythema if protective measures are not employed.

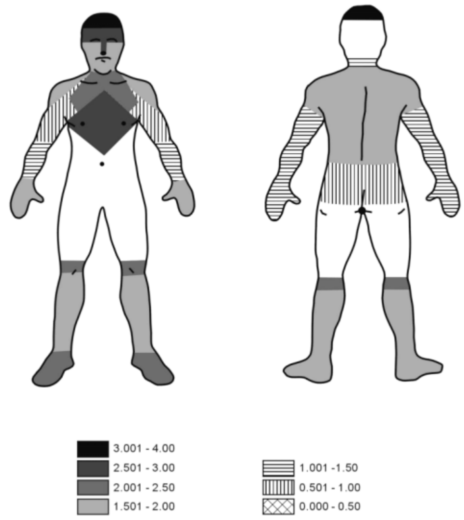


**Fig. 2**. Daily anatomical distribution of EUVR exposure (SED) for children and adolescents in Durban extrapolated from their measured daily lapel EUVR exposure (for details, see Guy *et al.*[11]).

## Conclusion

Comparing the anatomical distribution of EUVR has potential value for the design of sun protection interventions and establishing guidelines to reduce the incidence of skin cancer. Children and adolescents are an appropriate target population for such interventions, since learning safe-sun habits early in life is easier than reversing harmful practices later on.

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