Lower body anatomical distribution of solar ultraviolet radiation on the human form in standing and sitting postures

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Abstract

Humans undertake their daily activities in a number of different postures. This paper aims to compare the anatomical distribution of the solar erythemal UV to human legs for standing and sitting postures. The exposure ratios to the legs (ratio of the UV exposure to a particular anatomical site compared to the ambient) have been measured with UV dosimeters for standing and sitting postures of a manikin. The exposure ratios for the legs ranged from 0 to 0.75 for the different anatomical sites for the sitting posture in summer (December through February) compared to 0.14 to 0.39 for the standing posture. In winter (June through August) the exposure ratios ranged from 0.01 to 0.91 for sitting to 0.17 to 0.81 for standing. For the anterior thigh and shin, the erythemal UV exposures increased by a factor of approximately three for sitting compared to standing postures. The exposure ratios to specific anatomical sites have been multiplied by the ambient erythemal UV exposures for each day to calculate the annual exposures. The annual erythemal exposures to the anterior thigh and ankle were predicted to be higher than 800 MED for humans sitting outdoors each day between noon and 13:00 Australian Eastern Standard Time (EST). For humans standing outdoors during this time, the annual erythemal UV exposure averaged over each leg site was 436 MED, whereas, the averaged annual erythemal UV exposure was 512 MED for the sitting posture. Similarly, the annual erythemal UV exposure averaged over each of the sites was 173 MED for humans standing outdoors between 09:00 EST and noon each Saturday morning and 205 MED for humans sitting outdoors during this time. These results show that there is increased risk of non-melanoma skin cancer and malignant melanoma to the lower body if no UV preventative strategies are employed while in a sitting posture compared to a standing posture.

Keywords: UV, erythemal, posture, standing, sitting

INTRODUCTION

The solar UV exposures to selected human anatomical sites, for example the wrist and shoulder during normal daily activities has been measured using personal UV dosimeters [1-5]. Additionally, previous researchers have employed polysulphone dosimeters to determine the distribution of solar erythemal UV exposure to the human body in predominantly upright positions (for example, [4,6]).

Numerical models based on the exposure ratio or the ratio of the exposure to a specific anatomical site compared to that to a horizontal plane are used for the calculation of longer term UV exposures to humans [7,8]. Exposure ratios for predominantly upright postures have been measured (for example, [6,9,10]). Annual solar UV exposures have been calculated using these exposure ratios. This is necessary for aetiologic studies of skin cancer and other sun-related disorders and to determine the damaging influence of solar UV radiation.

Previous research has determined the dependence of the spectral biologically effective solar UV irradiances on sun-normal and horizontal planes [11]. The receiver orientation influences the solar UV exposures. Surfaces orientated in a sun-normal plane may receive up to 27% higher erythemal UV exposures. Humans undertake their daily activities in a number of different postures. For example walking and gardening have very different postures, although both activities are undertaken outdoors. Consequently, it is necessary to measure exposure ratios for human anatomical sites for postures other than predominantly upright. Exposure ratios have been reported for different postures in full sun for the upper leg [12]. However, more data is required for other sites of the leg. This is important in a number of settings for humans. Examples are spectators at sporting events, participants at sporting events, parents and friends as spectators at junior sports and people confined to wheelchairs. This paper compares the differences in the anatomical distribution of the erythemal UV exposures to the lower half of the body during sitting and standing postures.

MATERIALS AND METHODS

UV Dosimetry

The erythemal UV [13] exposures to specific human anatomical sites were measured using UV dosimetry techniques utilizing polysulphone film [14]. The polysulphone film was placed into a 25 mm x 25 mm plastic holder with an approximate 1 cm^2 central aperture. The polysulphone dosimeters were cast and fabricated by the authors at the University of Southern Queensland, Australia. The optical absorbance of the polysulphone film at 330 nm changes as a result of UV exposure causing degradation. The pre and post solar UV exposure optical absorbance of the polysulphone film was measured at 330 nm in a spectrophotometer (model UV 1601, Shimadzu Co., Kyoto, Japan). The pre and post exposure optical absorbance of the dosimeters was measured at four sites over the dosimeters in order to minimise the effects of surface variations and thickness changes over the surface of the film. Changes in optical absorbance following exposure were standardized by measuring the post exposure absorbance of all the dosimeters after a period of more than 24 hours following exposure. The overall error associated with polysulphone UV dosimetry is of the order of 10% [15].

The dosimeters were calibrated in units of MED (minimum erythemal dose). This was achieved through the exposure of a series of dosimeters on a horizontal plane near a calibrated erythemal UV meter (UV-Biometer, model 501, Solar Light Co., Philadelphia, USA). The MED is defined as the UV exposure producing barely perceptible erythema after 8 to 24 hours following UV exposure [7]. The erythemal UV meter provides the integrated erythemal UV for each 15-minute interval. The series of calibration dosimeters were exposed between 9.00 Australian Eastern Standard Time (EST) and noon. The broadband UV meter was calibrated on a seasonal basis through the direct comparison of recorded solar irradiances between the meter and a UV spectroradiometer. The calibration provided one MED as equivalent to 216 J m^{-2}. The spectroradiometer was calibrated against the primary UV irradiance based at the National Standards Laboratory, CSIRO, Lindfield Australia.

UV Exposure Distribution

Polysulphone dosimeters were placed on a manikin at each of the following sites: left thigh anterior and posterior, right thigh anterior and posterior, left shin anterior and posterior, right shin anterior and posterior. The manikins were used in this study as ethical issues, such as overexposure to solar UV prevented the use of humans as subjects in a series of experiments. Previous researchers (for example, [6,9]) have employed manikins in the measurement of solar UV exposures to the human body. The manikins with the attached polysulphone dosimeters were deployed in an open sports field between 09:00 EST and noon at a sub-tropical latitude in Toowoomba (latitude 27.5 ^{o}S and 693 m above sea level), Australia. For this location, the surface albedo of the grass was approximately 5% and the nearest buildings were more than 30 m away from the experiment site. For each exposure period, two dosimeters were exposed in full sun on a horizontal plane for the calculation of the exposure ratios. The exposure ratios to specific anatomical sites vary with the seasons due to the different solar zenith angles and atmospheric conditions, consequently, for this research, a set of measurements was made in the southern hemisphere summer and a set in the winter.

In this experiment, two manikins were used. The first set of UV exposure measurements consisted of one manikin in an upright position and the other manikin sitting on a chair, with both exposed to full sun conditions. The manikins were sufficiently spaced from each other so that there no was no mutual shading. Both manikins were rotated clockwise by ninety degrees every 15 minutes to minimise any directional effects, such as over exposure to one site, and also to replicate the effect of human random orientation to the sun when outdoors. Previous comparisons of the UV received by rotating manikins and humans undertaking normal outdoor activities have shown that the UV exposures to the manikin cheek, hand and thigh provide a good approximation of the UV exposures to these sites on humans [16]. The manikin UV measurements overestimate the exposures to the shoulder and sternum and underestimate the exposure to the lumbar spine and upper arm, probably due to a tendency of humans to stoop forward and outstretch the arms and a preference to turn away from the direct sun. In this case, it was impractical to place the manikins on a rotating platform, so they were manually rotated every 15 minutes. The second set of exposures consisted of the manikins each in a standing and sitting position in tree shade. The manikins were again moved clockwise ninety degrees throughout the exposure period and also moved to follow the shade cast by the tree, in a similar manner to humans.

The dates of the exposures in the summer were 26 and 27 February, 2001 for the two postures in the full sun and in tree shade respectively. This was repeated in the winter on 21 June and 1 August for the two postures in the full sun and in tree shade respectively. The ranges of solar zenith angles between 09:00 EST and noon were 19 to 48^o and 45 to 66^o in summer and winter respectively.

The tree species used in this study was a *Cinnamomum camphora*. The denseness of the tree canopy was estimated by measuring the reduction of the irradiances in the visible waveband in the tree shade compared to the visible irradiances in full sun, using a similar technique to Parisi et al. [17]. The shade was not dense shade with sun flecks in the shade. The irradiances measured in the tree shade were 15% of those in the sun.

Scenarios

To quantify the differences in the annual UV exposures for the two postures to each site UV(S), a numerical model based on previous models [7,8] has been employed as follows:

$$UV\ (S) = \sum_i ER_i(S).AE_i \qquad (1)$$

where AE_i is the ambient erythemal UV exposures on an unshaded horizontal plane for the i th day and that has been summed over each 15 minute interval of the day, $ER_i(S)$ is the exposure ratio for each site during the i th day. The exposure ratios for each respective site in summer and winter have been linearly interpolated to provide those for the intermediate days. This assumes these days have similar atmospheric parameters such as ozone levels and cloud cover.

With this model, various hypothetical scenarios for the UV exposures can be considered, as follows:

- Scenario 1 – A group of the population who spends time between noon and 13:00 EST outdoors in full sun for each day of the year in an upright posture, either standing or walking with the remainder of the time of day spent indoors. This scenario is designed to represent indoor workers who spend the lunch hour outdoors standing or walking;
- Scenario 2 - The same group of the population as scenario 1 who spend the lunch hour sitting outdoors in full sun. This scenario is designed to estimate indoor workers who spend a lunch hour outdoors in a sitting posture while relaxing or eating lunch;
- Scenario 3 - A population group who spends the time between 9:00 EST and noon on each Saturday morning outdoors in full sun in an upright posture and spends the remainder of the time indoors. This scenario is used to reflect the situation for indoor workers who spend a morning each weekend, playing an outdoor sport where they are mainly in an upright posture, for example cricket or baseball;
- Scenario 4 - A population group who spends the time between 9:00 EST and noon on each Saturday morning outdoors in full sun in a sitting position and spends the remainder of the time indoors. The time spent outdoors may be as spectators at their children's or friends' weekend sporting activities or as spectators at major sporting events;
- Scenario 5 – The same group as scenario 1, except they spend the time either standing or sitting in tree shade either as a sport’s spectator or relaxing;
- Scenario 6 – The same group as scenario 4, except they spend the time either standing or sitting in tree shade.

Analysis of these scenarios are important due to the skin damage resulting from intermittent UV exposures on relatively unprotected skin.

RESULTS

UV Exposure Distribution

The erythemal UV exposures between 9:00 EST and noon to the six sites on the lower body for the three hour exposure period in summer are shown in Table 1 for each of the two postures in full sun. For the anterior thigh and shin, the exposure increased by a factor of approximately three for sitting compared to standing. In comparison, the exposure dropped to zero for the posterior thigh due to this site being between the leg and the chair, and the chair acting as a shading device for this site. The exposure was reduced by a factor of ten for the posterior shin while sitting. This is due to the shading to this site by the top of the chair and the upper part of the leg. The exposure to the posterior ankle for this posture was reduced by a factor of approximately two due to partial shading of this site by the higher parts of the leg. The exposures for the standing and sitting postures in the tree shade are provided for comparison in the final two columns. In the tree shade, the sitting/standing ratio is 1.6 for the anterior thigh and 1.4 for the anterior ankle. Again the exposure to the posterior thigh is negligible. The differences compared to full sun are due to blocking of the direct component and the high relative proportion of diffuse radiation in tree shade [18].

The exposure ratios for the two postures in full sun in summer and winter for each of the sites are shown in Figure 1. Error bars are shown as ±20% and are calculated as the accumulation of the ±10% error in the polysulphone measurements. As expected from the relative exposures in Table 1, the exposure ratios for the anterior thigh, shin and ankle for the sitting posture are higher than those for the standing posture. Conversely, the exposure ratios are lower for the posterior of the thigh, shin and ankle in the sitting posture. The corresponding exposure ratios for the tree shade are provided for comparison in Figure 2. Again the highest exposure ratios for the sitting posture are to the anterior of the thighs, shins and ankles. The exposure ratios in the tree shade for these sites are generally half of those in the sun. In comparison, the exposure ratios for the standing posture in both the sun and the shade vary less across each of the sites.

Scenarios

The annual erythemal UV exposures for the group of the population who spend an hour outdoors between noon and 13:00 EST for each day of the year with the remainder of the time spent indoors are shown in Figure 3 for scenarios 1 and 2. For the sitting posture the highest annual exposures were to the anterior thigh and anterior ankle with annual exposures higher than 800 MED. These exposures are higher than those for the standing postures for the corresponding sites due to the angle of the anterior of the thigh being on approximately a horizontal plane for sitting and the anterior of the ankle being on approximately 45 degrees to the horizontal. The exposures to the anterior of the shin are also higher for sitting compared to those for standing. This is due to the shin being at an angle between the vertical and 45 degrees to the vertical. This places the shin at an angle that is closer to the normal to the sun, causing the higher exposure. Figure 3 also provides the annual erythemal UV exposures for scenario 5. The highest exposures are between 300 and 400 MED.

Figure 4 provides the annual erythemal UV exposures for the group of the population who spends each Saturday morning between 9:00 EST and noon outdoors as either sport’s participants or spectators. The annual exposures are in excess of 350 MED to the anterior of the thigh and the ankle. Figure 4 also provides the annual exposures for scenario 6 with the highest exposures of approximately 150 MED.

DISCUSSION

The anatomical distribution to the lower body of the solar erythemal UV has been compared for the standing and sitting postures of a manikin. The exposure to each site was dependent on the particular anatomical site orientation. This distribution over the body has been measured for solar zenith angles between 19^o and 48^o in summer and between 45^o and 66^o in winter. The exposure ratios for all sites measured ranged from 0 to 0.75 for the sitting posture in summer compared to 0.14 to 0.39 for the standing posture. In winter the exposure ratios ranged from 0.01 to 0.91 for sitting to 0.17 to 0.81 for standing. Solar UV exposures in the tree shade were found also to be dependent on the body posture, however the range of exposure ratio values was less than that for full sun. The exposure ratios will not be the same for trees of canopy density different to the one used in this project due to the differing diffuse component of trees with a higher canopy density. However, the exposure ratios for the tree were provided to highlight the change in exposure ratios for the case when the relative proportion of diffuse UV is increased relative to the direct component.

The annual erythemal exposures to the anterior of the thigh and ankle were higher than 800 MED to each site for scenario 2. Averaged over each day, this is over 2 MED for the one hour period of exposure outdoors. These are in excess of occupational exposure limits for UV exposure [19]. The erythemal UV exposures to different population groups have been previously measured at this location by other researchers [3]. The median of the daily erythemal UV exposures to the shoulder for outdoor workers, school children and home workers during normal daily activities were 3.0, 1.5 and 1.2 MED. At a similar latitude, daily erythemal exposures of 3 to 5 MED have been measured to the shoulder and chest of lifeguards, school grounds staff and physical education teachers [4]. For the standing posture of scenario 1, the annual erythemal UV exposure averaged over each site was 436 MED, whereas, the averaged annual erythemal UV exposure was 512 MED for the sitting posture of scenario 2. Similarly, the annual erythemal UV exposure averaged over each of the sites was 173 MED for the standing posture of scenario 3 and 205 MED for the sitting posture of scenario 4. Skin acclimatization such as skin thickening and pigmentation would lead to considerable lower cumulative MEDs. Long-term dosimetry does not take into account dynamic changes in skin sensitivity, however it provides information on the relative exposures to each site for each posture. These exposures averaged over each site are higher for the sitting posture due to the receiver orientations of the sitting posture. In comparison for the tree shade, there are also differences in the exposures for the standing and sitting postures, however the differences are not as high as for full sun exposure.

The UV distribution over a human varies with solar zenith angle, atmospheric composition and ground albedo. However, in this project, the exposures from 9:00 EST to noon in both summer and winter take into account solar zenith angles between 19^o and 66^o in clear sky conditions. Nevertheless, further research is required to collect data on the exposure ratios for each month of the year and different atmospheric conditions and surface albedo. Additionally, humans sit in a variety of different postures and the exposure ratios may possibly vary for different sitting postures. The results presented are for one sitting posture only. Nevertheless, they provide a first order of magnitude evaluation of the differences in the exposure ratios and differences in UV exposures. Further research is required to quantify the exposure ratios for possible different sitting postures.

This research has shown that people outdoors in a sitting posture will receive higher exposures to the legs compared to people in a standing posture if no UV preventative strategies are employed. Additionally, the exposures to some specific leg sites increases by approximately a factor of three. Spectators at sporting events, people sitting outdoors relaxing and people that are confined to wheelchairs will have increased risk of non-melanoma skin cancer and malignant melanoma if no protective measures against over exposure to solar UV radiation, such as clothing or sunscreen are employed.

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Table 1 – Comparison of the erythemal UV exposures to the lower body for the standing and sitting postures in sun and tree shade in summer between 09:00 and 12:00 EST.

	Erythemal UV Exposure (MED)			
	Sun		Tree Shade	
	Standing	Sitting	Standing	Sitting
Anterior Thigh	3.5	10.1	2.2	3.5
Posterior Thigh	2.8	0.0	1.9	0.1
Anterior Shin	2.3	6.8	2.0	3.8
Posterior Shin	5.4	0.5	2.1	1.1
Anterior Ankle	5.6	9.5	2.8	3.9
Posterior Ankle	4.3	2.3	2.2	1.4

Figure Captions

Figure 1 - Exposure ratios (ER) for the human leg sites while standing and sitting in full sun for summer and winter.

Figure 2 - Exposure ratios (ER) for the human leg sites while standing and sitting in tree shade for summer and winter.

Figure 3 – Annual erythemal UV (UVery) exposures between noon and 13:00 EST in full sun for the standing and sitting postures of scenarios 1 and 2 and in tree shade for the standing and sitting postures of scenario 5.

Figure 4 - Annual erythemal UV (UVery) exposures for each Saturday between 9:00 EST and noon in full sun for the standing and sitting postures of scenarios 3 and 4 and in tree shade for the standing and sitting postures of scenario 6.

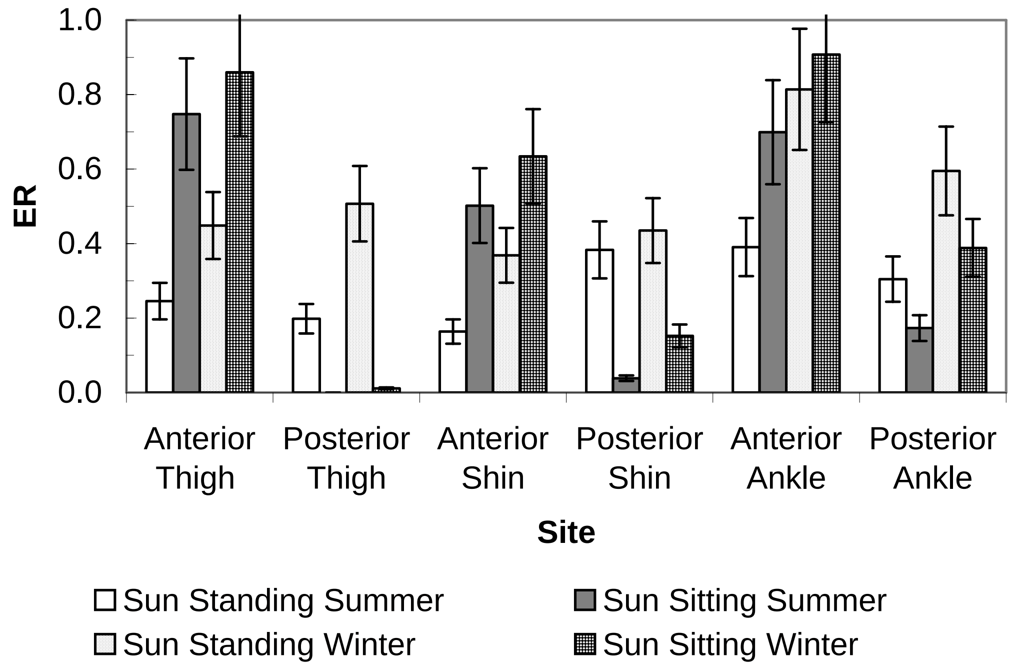

Figure 1 – Exposure ratios (ER) for the human leg sites while standing and sitting in sun for summer and winter.

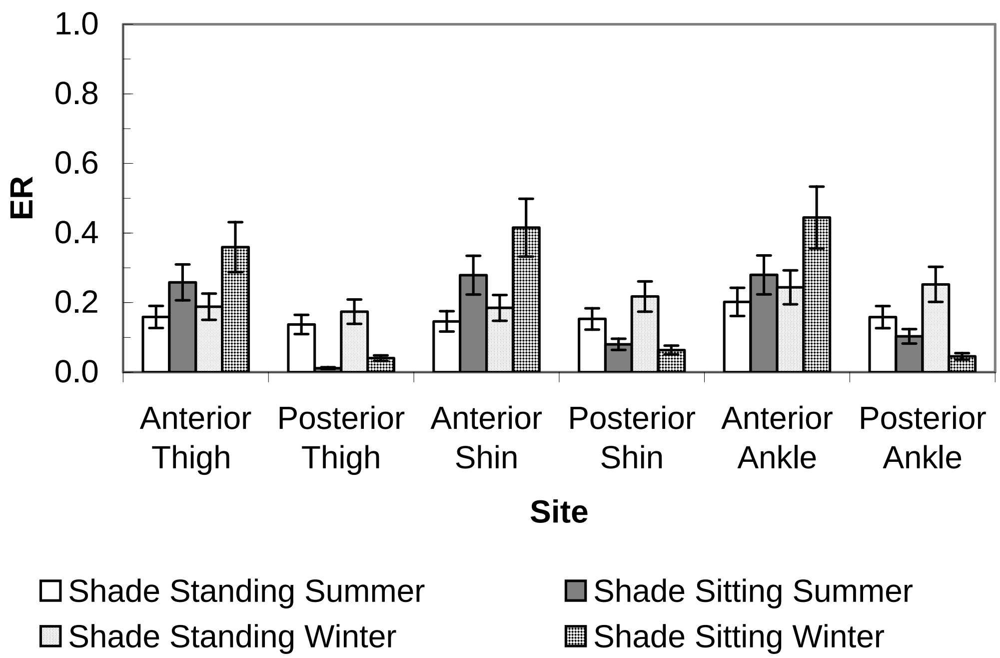

Figure 2 - Exposure ratios (ER) for the human leg sites while standing and sitting in tree shade for summer and winter.

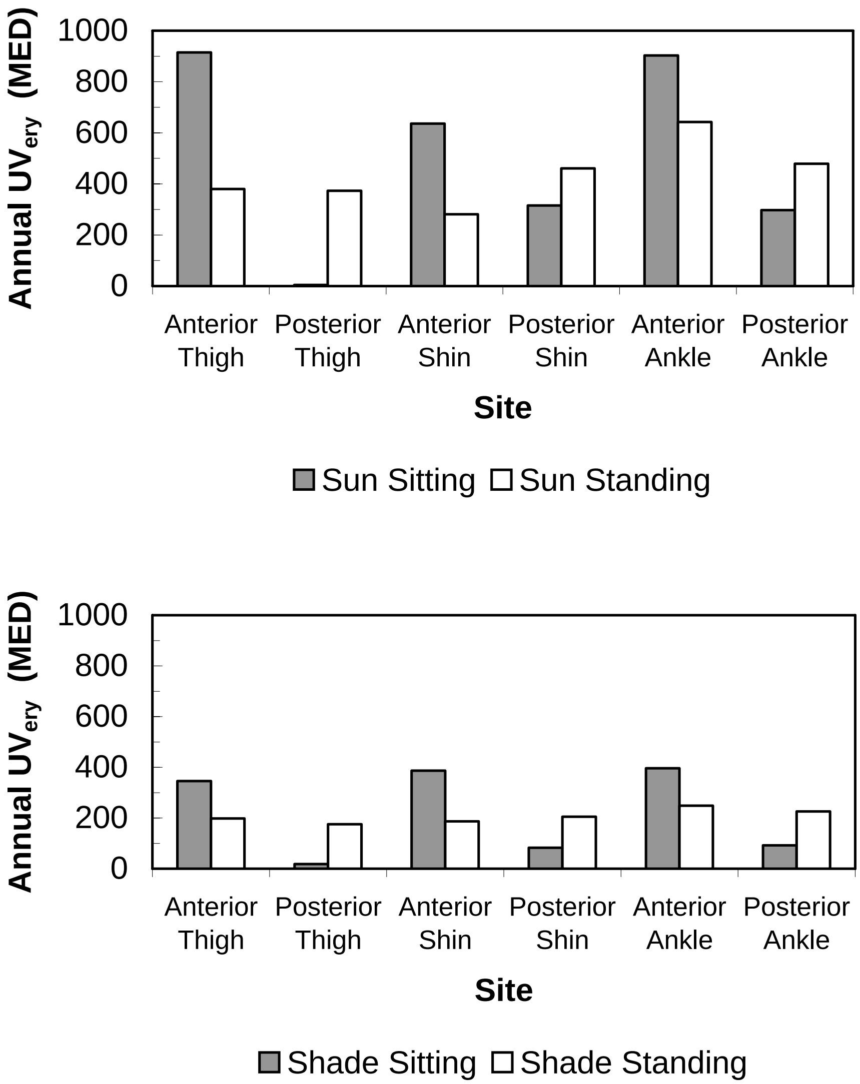

Figure 3 – Annual erythemal UV (UV$_{ery}$) exposures between noon and 13:00 EST in full sun for the standing and sitting postures of scenarios 1 and 2 and in tree shade for the standing and sitting postures of scenario 5.

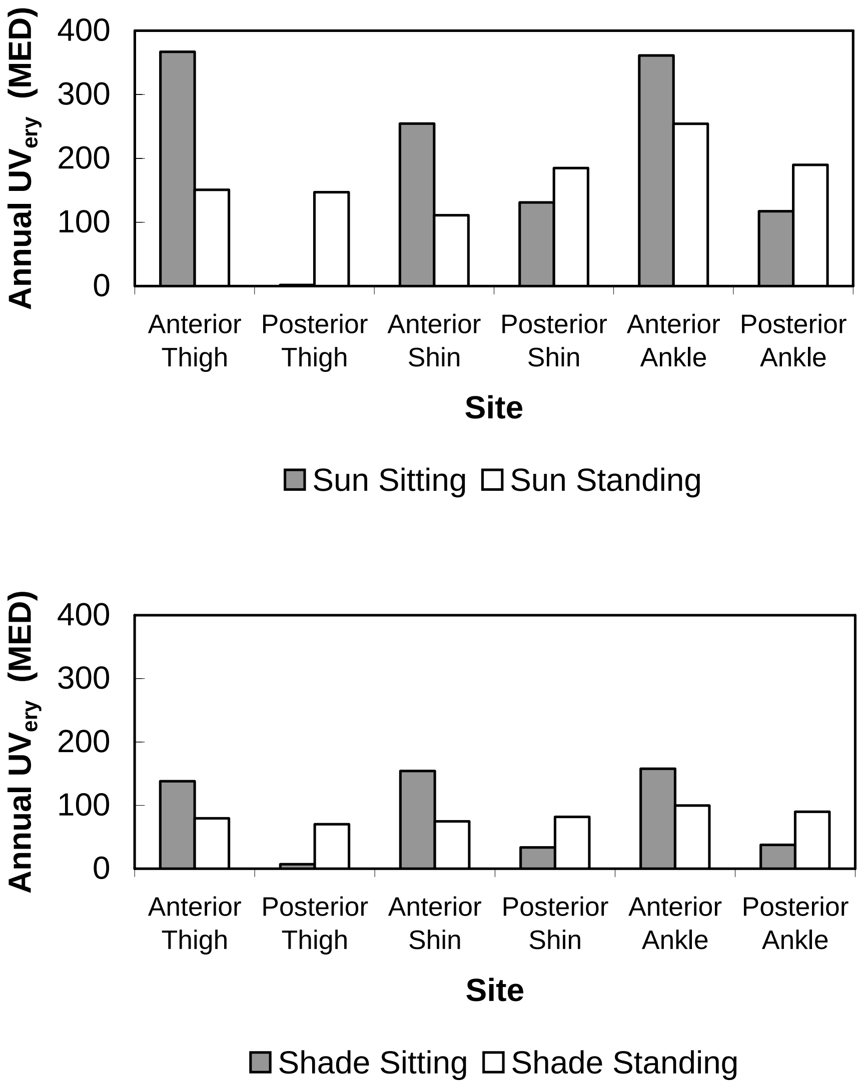

Figure 4 - Annual erythemal UV (UV_{ery}) exposures for each Saturday between 9:00 EST and noon in full sun for the standing and sitting postures of scenarios 3 and 4 and in tree shade for the standing and sitting postures of scenario 6.