Modelling the erythemally effective UV to students in a school environment

N.J. Downs[1], A.V. Parisi[1]
[1]Department of Biological and Physical Sciences, University of Southern Queensland, Toowoomba, Australia.

Abstract
A technique to represent erythemally effective solar ultraviolet radiation incident on exposed surfaces of the human body has been developed from laser scans of manikin body part models. Variation in manikin topography has been modelled for three dimensional visualisation of the received biologically effective solar UV exposure to the face, neck, arms, hands and legs. Exposures to each of the modelled regions have been extensively measured at specific manikin sites using polysulphone dosimeters. The measurement sites allow the formation of a network of contours over the body to display erythemally effective solar UV exposure relative to the modelled incident horizontal plane solar UV irradiance. The developed contour models of the face, neck, arms, hands and legs can be placed into a modelled school environment to represent the likely erythemally effective exposure received by school children using that environment. The playground environment at Hervey Bay State High School (25^{o}S,153^{o}E) was the first to be modelled for this research using a photographic survey technique to determine sky view and local surface reflectivity within the school playground to a site resolution of 5 m. This survey, applied to any number of school playgrounds or outdoor settings has the potential to provide UV hot spot maps that detail variation in local environments with variation in season, time of day, and cloud cover. When weighted to the developed body contour models, realistic estimates of cumulative UV exposure can be given for children using those environments.

Keywords: Ultraviolet; Dosimetry; School Environment

Introduction
Outdoor school environments present a significant skin cancer risk to Australian children. The association between chronic exposure to solar ultraviolet (UV) and the development of non melanoma skin cancer (NMSC) is readily recognised. Furthermore, chronic exposure and a past history of severe sunburning episodes experienced during childhood and adolescence have been recognised as significant risk factors for the later development of melanoma skin cancers (Armstrong 1988; Elwood and Jopson 1997; Longstreth *et al.* 1998). Australia has the highest skin cancer rate in the world, reporting a total of 1536 skin cancer related deaths in 2003, with the approximate number of melanoma skin cancer deaths being just over 1000 annually (AIHW and AACR 2007). Children placed in a school environment between 9:00am and 3:00pm experience a significant proportion of the daily solar UV exposure which peaks around noon when the sun reaches its highest elevation. Exposure limits in guidelines for occupational exposure to UV incident on the skin and eyes are exceeded after 26 minutes for a UV index as low a 3 and within 7 minutes in fair skinned individuals for a UV index of 12 or greater which occurs typically near noon during the summer months (ARPANSA 2006). The benefits of UV exposure to the skin include the photolysis of pre-vitamin D_3 which is associated with the prevention of diseases including rickets, osteoporosis, osteomalacia and some cancers (Holick 2004; Grant 2002). A position statement issued 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 recommends exposures in Australia of five minutes solar UV exposure either side of the peak UV periods on most days of the week in summer and approximately 2-3 hours solar UV exposure over a week in winter. Schools, being controlled environments have the potential to play a very important role in guiding sun safe practices among an Australian population caused by childhood exposure to solar UV.

Understanding how the incident UV irradiance affects patterns of playground and body surface exposures can play an important role in reducing unnecessary exposures experienced by students in the school playground. The importance of sun protective strategies including the active use of hats, sunscreens and shade use has been extensively promoted by the various state cancer councils of Australia with the message being actively pursued by many schools involved in the 'SunSmart' program (Montague *et al.* 2001). This research extends upon existing sun protective strategies introduced into schools by providing a model that can predict day to day playground and body surface UV exposures. It is anticipated that the developed model could assist schools with the planning and scheduling of outdoor events such as sports carnivals and provide students with day to day advice on playground UV hot spots.

The playground model presented in this research has been developed from site measurements of playground sky view, shading and UV reflection (albedo) caused by ground and standing surfaces. Each of these influences are factored into the horizontal plane UV irradiance playground exposure which was modelled using additional horizontal plane inputs. These inputs were atmospheric parameters including, variation in cloud cover, ozone, air and aerosol species concentrations, and geographical parameters including altitude, and daily variation in solar zenith angle (SZA) affected by latitude (Downs *et al.* 2008). Horizontal plane playground exposures modelled in the playground environment have further been weighted to exposure measurements of the face, neck, arm, hand and leg to provide estimates of body surface exposure that can be modelled for any given time period within any playground location.

Materials and Methods

The school grounds of Hervey Bay State High School (HBSHS) were surveyed at 822 sites to produce the playground exposure model for this research covering an approximate area of 6.5 ha. The school ground contains two large open fields or playground ‘ovals’ at the eastern end of the playground and has 20 buildings located in proximity to one another at the western end of the playground. The school ovals and grounds between buildings are accessible to students during meal breaks and periods of outdoor physical education classes. Approximately 80% of the playground surface is grass with 4% being covered by garden beds which are largely inaccessible to students with the remainder being covered by hard surfaces. The modelled school runs four 70 minute teaching classes and two free 40 minute meal breaks between 9:00am and 3.05pm from late January through to early December each year. The playground was divided into 25 regions, each representing areas with similar ground surfaces and structures that were frequented by students daily. Estimates of UV playground exposure were calculated for each of the 25 regions. Body surface exposures for the face, neck, arm, hand and leg were estimated based on the mean statistics for each region. Region playground statistics included mean ground surface albedo, mean standing surface albedo, mean sky view and mean shade density. Body surface estimates of the erythemally effective UV were further compared with surface UV exposures measured on a cohort of the HBSHS student population for dosimeter sites located on the face, neck, arm, hand and leg, totalling 147 measurements between February and June 2008 following approval by the USQ human research ethics committee and permission from the school principal.

Modelling the playground UV exposure

Fig.1a shows each of the sky view sites surveyed in the HBSHS playground. A series of 16 photographs were taken at each survey site under clear sky conditions using a Digital SLR camera (50 mm lens) at f11 (Canon EOS 350D). Site composite images were formed from each site series covering an area of 0^o to 360^o in azimuth and 90^o to 32^o in SZA. Site sky view was calculated by separating playground surface objects from the sky by measuring the Blue-Red threshold of each pixel imaged above the horizon in the composite site image (Downs *et al.* 2008). The position of the solar disk was placed onto the processed site sky view image to determine playground shade density. Playground sky view and shade density is given in Fig. 1b and Fig. 1c respectively for the school’s pool region. Fig. 2a shows one site image taken within the school’s pool region. Fig. 2b shows the plotted position of the solar disk for 15 February 2008 at the times 9:00am, 10:00am, 11:00am, 12:00pm, 1:00pm, 2:00pm and 3:00pm. The position of the solar disk, superimposed over each survey site was used to determine playground shade density.

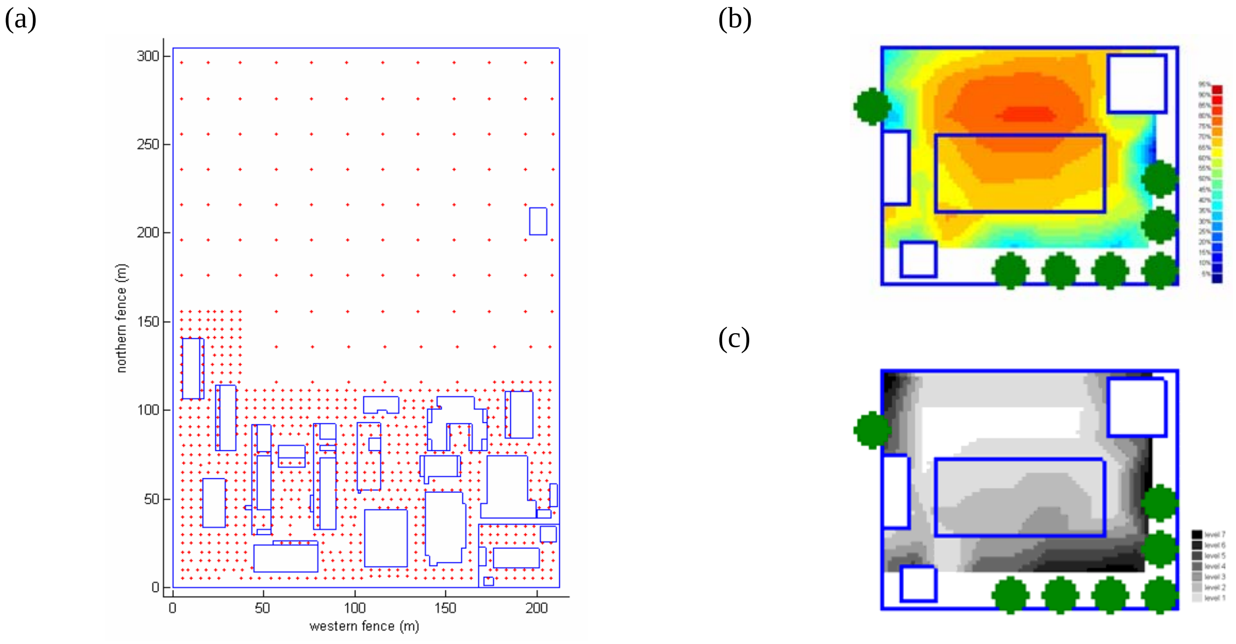

Figure 1: (a) Playground survey sites; (b) pool region sky view; (c) pool region shade density between 9:00am and 3:00pm on 15 February 2008 (circles give the positions of trees in the pool region of the playground).

(a)

(b)

Figure 2: (a) A composite image of a site located in the pool region. (b) The pool region site sky view and solar position estimated for 9:00am, 10:00am, 11:00am, 12:00pm, 1:00pm, 2:00pm and 3:00pm, 15 February 2008.

Modelling body surface exposure

Body surface exposures were measured at 1453 sites on a life sized manikin measuring 178 cm in height. The manikin was taken to represent a high school student and was placed in an upright position on a rotating base that was exposed to solar UV in the SZA ranges, 0^o to 30^o, 30^o to 50^o and 50^o to 80^o under clear and cloud covered conditions at the University of Southern Queensland's Toowoomba campus (28^oS, 152^oE). Body surface exposures were expressed relative to the horizontal plane exposure for each of the face, neck, arm, hand and leg. Measurements of body surface exposure expressed relative to the horizontal plane exposure were measured in a campaign extending from 2005 to 2008. A total of 2491 mean body surface exposures were used to develop three dimensional wireframe maps of exposure to the face, neck, arm, hand and leg. The horizontal plane playground exposure estimate was weighted to each of the respective body surface exposures for the respective SZA range in the exposure period and expressed relative to the horizontal plane.

Results and Discussion

Fig. 3 represents the body surface pattern in UV exposure for a subject using the pool region between 9:00am and 3:05pm, 15 February 2008. The total UV exposure is expressed in units of Standard Erythema Dose (SED), where 1 SED represents 100 Jm^{-2} of erythemally effective UV. The exposure pattern presented in the figure was calculated as the mean UV horizontal exposure of each pool region playground site in the period between 9:00am and 3:05pm. For Fig. 3, the mean horizontal plane exposure modelled over each of the 46 pool region survey sites was 34.1 SED. This exposure is represented as the maximum exposure in Fig. 3 and occurs at the vertex. Exposures exceeding 17 SED are also evident in the figure on the nose, and dorsa of the arm and hand. The inclusion of the direct UV component in the calculation of the mean pool region exposure (Fig. 3) was dependent on the region shade pattern estimated for each of the periods listed in Table 1, whereby the direct component was not included in the horizontal plane exposure estimate for each survey site if the solar disk was obscured by a surface structure. The total diffuse UV component (Table 1) was weighted to each survey site sky view. The range in horizontal plane exposure estimated for the pool region on 15 February 2008 was from 4.8 SED to 47.4 SED.

Table 1: **Modelled horizontal plane direct and diffuse UV for 15 Feb 2008 (unshaded, 100% sky view).**

Period	**Direct UV exposure (SED)**	**Diffuse UV exposure (SED)**
9:00am to 10:00am	2.5	3.5
10:00am to 11:00am	3.9	4.8
11:00am to 12:00pm	4.9	5.5
12:00pm to 1:00pm	4.9	5.6
1:00pm to 2:00pm	4.1	4.9
2:00pm to 3:05pm	2.8	3.9
Total	23.1	28.2

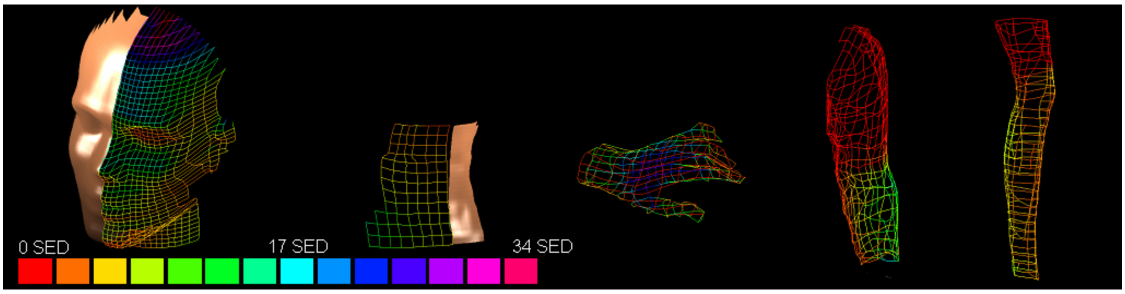

Figure 3: Modelled surface exposure in the pool region, 15 February 2008. Exposures of 0 SED evident on the upper arm and thigh were due to clothing protection by the school uniform worn by the manikin.

The erythemally effective UV exposure measured to exposed skin in the student population during the school's annual swimming carnival (15 February 2008) varied from between 32.0 SED to 49.8 SED on the vertex and 4.9 SED to 15.8 SED on the forearm. These measurements are within a reasonable tolerance of the estimated horizontal plane erythemally effective swimming pool region exposure of between 4.8 SED modelled in a location situated in full shade during the exposure period and 47.4 SED modelled for a location situated in full sun. Additional variations between the modelled and measured UV exposure during the 9:00am to 3:05pm period include differences in ozone and aerosol species concentrations and uncertainty in dosimeter measurements.

Conclusions

Estimates of the erythemally effective UV exposure received by unprotected skin surfaces of the body can be modelled using the technique presented for any playground environment considering the limitations that will always be present due to an individual's movement and behaviour. Playground exposures and the subsequent UV exposures predicted for unprotected body surfaces have been developed from playground site measurements and measurements of body surface UV exposure. These measurements detail the influence of shading caused by the human form and detail variation in exposure over human surface topography to a high resolution not able to be measured on living human subjects alone. This data set represents the most extensive set of body surface UV exposures available that can be applied to predict patterns in body surface exposure with seasonal and daily variation in solar elevation. Structures present in the playground such as individual trees and buildings are accounted for by survey measurements made in the playground, extending existing techniques used to model the effects of playground shading alone. The benefits of modelling the erythemally effective UV to students in a school environment include making assessments of long term UV exposure and providing added planning assistance that can be utilised to minimise UV exposures associated with school activities that use the playground environment.

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