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Ultraviolet Radiation Exposure of Children and Adolescents in Durban, South Africa¶

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ABSTRACT

The solar ultraviolet radiation (UVR) exposure of 30 children and adolescents in three age groups (4–6 years, 7–9 years and 13–14 years) was measured for 1 week in late summer (February–March) in Durban, South Africa, using UVR-sensitive polysulfone film badges (PSFB) attached to the lapel region of the body. The mean and median values for all ages over the study period were 2.0 and 1.2 standard erythemal dose (SED) units, respectively, where 1 SED = 100 J·m^{-2}. Individual PSFB doses were analyzed as a function of age, gender and behavior. No significant statistical differences were found between different age groups; however, there was a statistical difference between males and females, with males generally receiving higher PSFB doses. Subjects completed UVR exposure journals documenting their time outdoors, shade *versus* sun conditions, nature of their activities, clothing worn and their use of sunscreen for each day of the study. Activity patterns were noted as the most important factor influencing individual UVR dose. Ambient erythemal UVR was measured by a Yankee Environmental Systems UVB pyranometer, and a relationship between ambient UVR and individual UVR dose was derived. On average, subjects received a dose of 4.6% of the total daily erythemal UVR. Based on this factor, the potential dose of an individual over a full annual cycle was estimated. Accordingly, there were 139 days during the year when an individual with skin type I (light skin) would be likely to experience minimal erythema and 97 and 32 days for individuals with skin types II and III, respectively.

INTRODUCTION

Stratospheric ozone plays an important role in absorbing solar ultraviolet radiation (UVR) and hence in reducing the amount of UVR received at the earth's surface. Depletion of the ozone layer has raised concern about an expected increase in surface UVR levels. Although downward trends in total column ozone are widely documented, including South Africa (1–3), corresponding upward trends in surface UVR are not as readily detectable because the UV band comprises a relatively small portion of the electromagnetic spectrum (UVA [320–400 nm] ~ 6.3%; UVB [280–320 nm] ~ 1.5%) (4). However, a number of studies have noted an inverse relationship between total column ozone and surface UVR, including Herman *et al.* (5), Bodeker and Scourfield (3) and Prause *et al.* (6).

Overexposure to relatively high levels of surface UVR is known to have adverse effects on biological systems. The effects of increased UVR on human health include photoaging of the skin, erythema, cataracts and skin cancer (7–9). There are two types of skin cancer: nonmelanoma skin cancer, including basal cell carcinoma and squamous cell carcinoma, and malignant melanoma skin cancer (MMSC).

Many studies have noted a relationship between childhood UVR exposure and the development of skin cancer, particularly MMSC, during adulthood (10–16). Overexposure to UVR before the age of 20 years is thought to increase this risk, particularly in terms of developing MMSC (13,17).

Cancer statistics indicate that, when compared with other countries, South Africa has one of the highest skin cancer rates in the world (18). For this reason, a study investigating UVR exposure in South Africa is justifiable. Recognition that childhood exposure plays a significant role in increasing the risk of skin cancer underlines the importance of focusing on the UVR doses and exposure patterns of children and adolescents to assess the personal risk and to determine preventative methods. This study will focus on young children and adolescents residing in the city of Durban, South Africa.

Similar studies recording individual UVR doses and exposure patterns have been undertaken elsewhere. For example, Diffey *et al.* (11) measured the UVR doses of children aged 9–10 years and 14–15 years in three geographically distinct regions in England for a 3 month period during summer. Gies *et al.* (12) assessed the UVR doses of primary school children in Brisbane, Toowoomba and Mackay (Australia) for a 2 week period, and Moise *et al.* (14) measured the UVR exposure of infants and small children living in Townsville, Australia. However, it is believed that the investigation described in this article is the first of its kind in South Africa.

The study aims to provide a measure of the UVR exposure of preprimary, primary and high school children during the school term. Objective measurements of UVR dose were obtained using UVR-sensitive polysulfone film (PSF). The relationship between

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Abbreviations: MED, minimal erythemal dose; MMSC, malignant melanoma skin cancer; PSF, polysulfone film; PSFB, polysulfone film badge; SED, standard erythemal dose; UVR, ultraviolet radiation; YES, Yankee Environmental Systems.

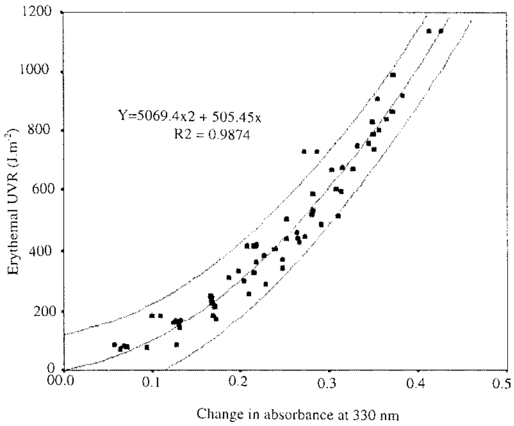

Figure 1. Dose–response calibration curves for PSF showing ΔA_{330} of PSF *versus* the YES UVB pyranometer erythemal UV dose, showing the measure of uncertainty with a 95% confidence band.

UVR dose and age, gender and behavior was also analyzed, as has been done in other studies. A unique feature of this research is the attempt to relate the individual UVR dose to the ambient UVR radiation and to discuss the annual risk of minimal erythema according to the skin type.

MATERIALS AND METHODS

Study location. Durban (30°S, 31°E; population of the greater Durban area is ~3 million) is located on the east coast of South Africa within the subtropical high-pressure belt and consequently receives relatively high levels of ambient UVR (3).

Ambient erythemal UVR and climate monitoring. Ambient levels of erythemal UVR, weighed by the Diffey action spectrum for human erythema, were measured continuously and averaged over 10 min intervals by a Yankee Environmental Systems (YES) broadband UVB pyranometer. Although erythemal UVR is universally recognized as lying between 280 and 400 nm, the YES pyranometer measures UVR for the wave band 280–320 nm and automatically weighs this by the above-mentioned action spectrum to give erythemal UVR. Details of the principles of operation of the instrument are given in Prause *et al.* (6) and Duigan *et al.* (19). The YES UVB pyranometer has a 5% uncertainty of spectral irradiance measurements (19). The instrument is located on the roof of a building (approximately 28 m high) at the University of Natal. Erythemal UVR (in $J{\cdot}m^{-2}$) was converted to standard erythemal dose (SED) units, where 1 SED was taken to be equivalent to 100 $J{\cdot}m^{-2}$ (20; B. L. Diffey, personal communication). Earlier studies have used the minimal erythemal dose (MED) unit, where 1 MED is equivalent to 200 $J{\cdot}m^{-2}$ for skin type II (11). Meteorological parameters, including mean hourly temperature, wind speed and direction, humidity and daily totals of sunshine hours and rainfall, were obtained from South African Weather Service for the meteorological station situated at Durban International Airport, approximately 12 km from the location of the pyranometer.

Recruitment of subjects. Three groups of subjects were identified using similar age breakdowns to previous studies by Diffey *et al.* (11) and Moise *et al.* (13). The three age groups were 4–6 years, 7–9 years and 13–14 years. Subject recruitment was done on a volunteer basis. A preliminary meeting was held with the relevant educator at each school, and the requirements of the study were discussed. A second interactive meeting was held with the educator's class to inform them of the study and to ask for volunteers to participate in the study. From this list of volunteers, 30 subjects were selected on the basis of their fulfillment of criteria such as age, interest and enthusiasm, responsibility and ability to keep accurate records and to comply with the requirements of the study. The adaptation of a purposive rather than a random sampling technique was done to ensure a high rate of return in the face of limited resources and the inability to repeat the study should any problems arise. It was assumed unlikely that the nature of subject selection would alter behavior because the subjects were governed by formal school activities, at least during the week. Consent forms were signed by each subject's parent or guardian, and ethics approval for the study was obtained from the Nelson Mandela School of Medicine, University of Natal, Durban, South Africa.

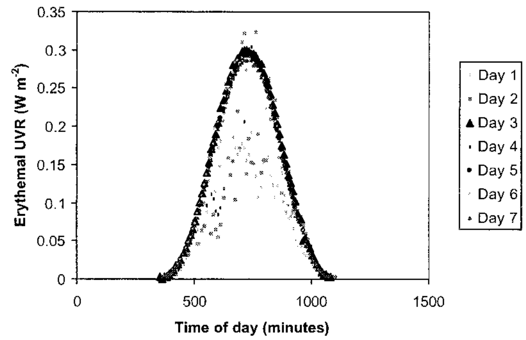

Figure 2. Diurnal variation in ambient erythemal UVR ($W{\cdot}m^{-2}$) as recorded by the YES UVB pyranometer in Durban for each day of the study period.

PSF as a UVR dosimeter. Davis *et al.* (21) first identified PSF as a reliable means of measuring individual UVR doses in 1976. It has since been widely used in many studies, including Diffey *et al.* (11), Holman *et al.* (22), Herlihy *et al.* (23) and Gies *et al.* (12,24). The PSF used in this study was 50 μm thick, with a spectral sensitivity between 280 and 330 nm. The absorbance of PSF changes on exposure to UVR, and by measuring this change in absorbance at 330 nm (ΔA_{330}), the degree of degradation may be quantified in terms of an erythemal UVR dose ($J{\cdot}m^{-2}$) through the application of a calibration equation. The calibration equation was derived through simultaneous measurements of ambient erythemal UVR using the YES UVB pyranometer, and erythemal UVR dose measured by the PSF. The postexposure absorbance measurements of the PSF strips used in the calibration procedure were undertaken 24 h after exposure. This was to allow for the darkness reaction to be completed (21) and for the PSF UVR dose to be a true representation of the UVR dose received. The calibration curve used in this study is presented in Fig. 1. It is clear from the scatter of individual points that the estimates of the erythemal UVR dose involve a measure of uncertainty, which is quantified by the 95% confidence limits. Pre- and postexposure absorbance measurements of the PSF were undertaken using a Varian DMS 300 UVR–visible spectrophotometer. Polysulfone film badges (PSFB) consisting of a strip of PSF placed in a cardboard mount with a medium-sized safety pin attached to one side of the mount were assembled. The central aperture was 1.2 × 1.6 cm. Each PSFB was numbered sequentially, the pre-exposure absorbance measurement at 330 nm recorded and the badges stored in a correspondingly numbered envelope that was impervious to UVR. One PSFB was worn per subject per day for 7 days between 26 February and 4 March 2001. The PSFB was attached to the left lapel site, *i.e.* clavicle or collarbone, in accordance with similar studies conducted by Diffey *et al.* (11; B. L. Diffey, personal communication) and Holman *et al.* (22). Subjects were instructed to ensure that the PSFB were never covered by clothing, were only removed during swimming activities and were replaced in their original envelopes at the end of each day. The postexposure absorbance measurements were done on 6 March 2001 once all the PSFB were returned to ensure that they were all retained in the dark for a minimum period of 24 h. A total of 202 PSFB were returned (96% return rate), of which 192 were used in the analysis, the remaining being damaged.

The UVR exposure journal. Each subject received a resource kit containing seven PSFB, an information sheet and a UVR exposure journal. The journal provided a general introduction to the study, an indication of the roles of the subject, educator and parent or guardian in the study, guidelines on wearing the PSFB, their handling sensitivities and instructions on how to record information in the journal. The journal was completed on a daily basis for seven consecutive days. Subjects between the ages of 4 and 9 years were required to work with an adult to complete the journal. The information collected in this manner provided a continuous record of the subject's activities throughout the day, including the timing and duration of each activity, whether it took place indoors or outdoors, and if the latter, whether in the shade or sun, in addition to the type of clothing worn and whether sunscreen was applied. It was assumed that the journal entries were a true representation of the subject's activities, although it is recognized that there was individual variability in the accuracy of record keeping.

Table 1. Daily total ambient erythemal UVR in joules per square meter and SED (1 SED = 100 J m^{-2}) units during the study period, as recorded by the YES UVB pyranometer

Day of study	Date	Julian day	Daily integrated erythemal irradiances (J m^{-2})	SED units
1	26 February 2001	57	6107.4	61.1
2	27 February 2001	58	4114.9	41.1
3	28 February 2001	59	4522.2	45.2
4	1 March 2001	60	6120.9	61.2
5	2 March 2001	61	5616.6	56.2
6	3 March 2001	62	5919.8	59.2
7	4 March 2001	63	5641.4	56.4
Mean			5434.8	54.3

On completion of the study, a follow-up meeting was held with all volunteers and educators, at which time the results of the study were presented and "safe-sun" behavior discussed. A formal report was also provided to each participating school.

RESULTS AND DISCUSSION

Ambient erythemal UVR and meteorological conditions

The diurnal variation in ambient erythemal UVR (W·m^{-2}) for each of the 7 days of the study period is shown in Fig. 2. The effect of clouds in reducing UVR levels to below the sinusoidal envelope is evident particularly on days 1 and 2. There is also evidence that UVR receipts can be enhanced by scattered cloud (*e.g.* around solar noon on day 2). Daily integrated ambient UVR irradiances and corresponding SED values are presented in Table 1. The mean value of 54.3 SED is typical of summer values in Durban and similar to the value of 52 SED recorded on a clear sky day in Tasmania in early February (23). Long-term studies including an analysis of the full annual cycle at Durban have been undertaken by Bodeker and Scourfield (3) and Duigan *et al.* (19).

Maximum ambient air temperatures for the study period ranged between 27.3°C and 31.2°C, whereas maximum relative humidity ranged between 81% and 91%. The combination of these two factors created particularly hot, humid conditions, which are believed to have influenced the study results.

Individual PSFB doses

The mean and median PSFB doses of all subjects for all days are 2.1 and 1.2 SED, respectively (Table 2). The 95% range (calculated as the mean ± 2 standard deviations) is 0.4–14.4 SED, indicating a large range in individual daily PSFB dose. On a day-to-day basis, there is little variation in the lower limit (0.2–0.6 SED); however, the upper limit ranges between 6.2 and 14.4 SED. The greater variability at the upper end is emphasized in Fig. 3 that depicts the minimum and maximum daily PSFB doses of each individual as a function of age. Ranked by maximum PSFB dose, it is evident that the minimum PSFB dose received by an individual of any age on any day varied little, being equivalent to or less than 200 J·m^{-2}. However, the maximum PSFB doses varied greatly with values reaching up to 1500 J·m^{-2} for the 7–9 years age group. The daily PSFB doses for adolescents were all less than 1000 J·m^{-2}, suggesting that children of preschool and preprimary school age receive potentially higher daily PSFB doses than adolescents. Diffey *et al.* (11) noted a similar finding for children between the ages of 9–10 years and 14–15 years.

These individual PSFB doses were lower than expected based on the ambient erythemal UVR recorded during this period (Fig. 2). The only explanation forthcoming at this stage is that the particularly hot and humid conditions played a role, causing subjects to seek shade and shelter rather than remain exposed in the sun. Nonetheless, the mean and median PSFB doses still exceeded the erythemal UVR daily exposure limit of 40 J·m^{-2} recommended by the International Commission on Non-Ionizing Radiation Protection and cited in Herlihy *et al.* (23), indicating that individual UVR doses were sufficiently high to pose a potential risk to their health according to this daily limit.

Influence of age and gender on PSFB dose

There is little difference in the mean and median PSFB dose as a function of age group (last three columns of Table 2), and statistical application of a nonparametric analysis of variance test revealed no significant differences at the 95% confidence level. There is some indication that the 95% ranges were smaller in the case of adolescents (0.4–10.0) than in the two younger age groups, most likely a reflection of the longer school day of high school students. A similar pattern was noted by Diffey *et al.* (11) for children aged 9–10 years and 14–15 years in a study conducted in England.

A comparison of the mean and median PSFB doses of male and female subjects (Table 2) showed that male subjects generally received higher PSFB doses than females, again confirming the findings of Diffey *et al.* (11). The mean (95% range in parentheses) and median daily PSFB doses for males were 2.4 SED (0.6–14.4) and 1.4 SED, whereas for females were 1.8 SED (0.4–12.6) and 1.0 SED, respectively. This was confirmed through the statistical application of the Wilcoxon two-sample test revealing a significant difference between the two groups at the 95% confidence level.

Influence of nature of activity on PSFB dose

The variability in individual PSFB dose was found to be dependent on the nature of activities in which an individual engaged. This was

Table 2. Mean, median and 95% range of daily PSFB doses (SED) of male and female subjects in three age group categories for all days of the study period

	Male			Female			All		
Age group	Mean	Median	95% range	Mean	Median	95% range	Mean	Median	95% range
4–6 years	2.2	1.4	0.6–7.2	2.2	0.6	0.4–12.0	2.2	1.2	0.4–12.0
7–9 years	2.0	1.2	0.4–14.4	2.2	1.4	0.6–12.6	2.0	1.4	0.4–14.4
13–14 years	2.6	2.2	0.4–9.2	1.4	0.8	0.4–10.0	2.0	1.2	0.4–10.0
All subjects	2.4	1.4	0.6–14.4	1.8	1.0	0.4–12.6	2.1	1.2	0.4–14.4

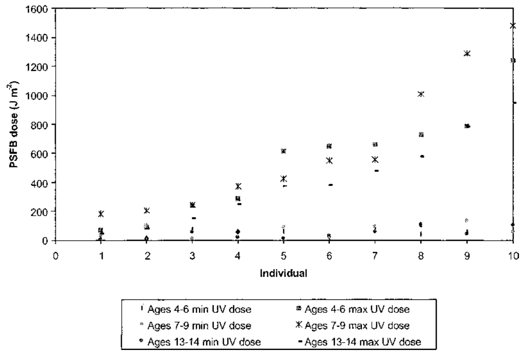

Figure 3. Minimum and maximum daily PSFB doses (J·m^{-2}) for each subject, ranked by maximum PSFB dose.

reflected first in the differences in PSFB dose on weekdays when compared with weekends (Table 3). The differences were most marked in the case of the two older age groups who were clearly able to spend more time on activities that involved greater UVR exposure on weekends than they were on weekdays. Differences were statistically significant in these cases but not in the youngest age group, which exhibited a more consistent daily UVR exposure.

Time spent outdoors is also a reflection of the nature of activity patterns. Based on the journal entries, the mean time spent outdoors for all age groups during the study period, including weekdays and weekends, was 2.3 h per day. This compares well with a similar study by Gies *et al.* (12), who found that Australian children spent on average 2.2 h per day outdoors during the school term. The time spent outdoors is seldom experienced as a single-exposure event but comprises intermittent brief exposure periods, which accumulate to a total of approximately 2 h. Although this represents a relatively small fraction of the day, the timing of exposure periods is critical in determining the intensity of PSFB dose received by an individual. Peak exposure frequently occurs between 10:00 and 11:00 A.M., a period that brackets the first tea break for all age groups in the daily school routine. The lunch break varies across age groups, accounting for the absence of a second dominant exposure period. After school closes (12:00, 1:15 and 2:30 P.M. for the three age groups) there is a wide range of activities undertaken, most of them of an outdoor nature. The contrast in exposure between afternoon and morning hours reflects this. Generally, before 10:00 A.M. the number of exposure periods based on the exposure of all subjects on all days of the study period is less than 40 per hour, whereas throughout the afternoon (after 12:00 P.M.) the corresponding value is above 60 per hour and often exceeds 80 per hour.

The range of outdoor activities of subjects included swimming (beach or pool), cricket, golf, cycling, tennis, spectator sports events, sun tanning, ball skills and playing in the playground or garden. Because the PSFB doses recorded the total daily erythemal dose of an individual, it was not possible to determine the UVR dose for particular activities. However, the 10 highest daily PSFB doses were analyzed to understand the influence of activity on daily UVR dose. Most of the activities (60%) related to swimming or beach activities and 70% of the highest doses occurred over weekends, when subjects were likely to have more time to engage in outdoor leisure pursuits. The adolescent age group also dominated these highest ranked PSFB doses. There is no relationship between length of exposure and PSFB dose, highlighting the complexity of factors influencing individual dose. Not only is timing of the exposure important but random human movement and orientation of the anatomic site toward the direct solar beam also influence PSFB dose. An experimental study in which an attempt is made to quantify the UVR dose as a function of anatomic site and activity is described in a companion paper (C. Guy *et al.,* unpublished).

Individual UVR exposure as a proportion of total daily ambient UVR

The determination of individual UVR exposure as a fraction of the total daily ambient erythemal UVR is a useful means of extrapolating the study results over a longer time period based on the assumption that the relationship remains constant over time (22,23).

Table 3 lists the mean and median PSFB doses as a percentage of the total daily ambient erythemal UVR for weekdays and the weekend for each age group. The weekend percentages for each group are greater than weekday values, particularly for the two older age groups. The mean percentage of the total daily ambient erythemal UVR for all the subject's PSFB doses for all days of the week was 4.6%. This is thought to be a conservative estimate and would change with various factors including solar zenith angle, time spent outdoors, etc.; however, this compares well with the mean value of 5% estimated by Diffey *et al.* (11). A frequency distribution of the PSFB doses as a percentage of the total daily ambient erythemal UVR for all subjects on all days reveals a peak frequency of 27.2% for the 1–1.9% range. The results did not exhibit a normal distribution and were skewed toward the lower percentages with 83.3% of the PSFB lying below 9% of the total daily ambient erythemal UVR. The relatively large number of extremes (6.3% have a PSFB dose >16% of the ambient erythemal UVR) is noted.

To provide an estimate of the annual variation in PSFB dose, the factor of 4.6% was applied to daily ambient erythemal UVR as

Table 3. Mean, median and 95% range of the daily PSFB doses (in SED) for weekdays and weekend days. Figures in parentheses represent the PSFB dose expressed as a percentage of the corresponding ambient erythemal UVR dose

	Weekday			Weekend		
Age group	Mean	Median	(95% range)	Mean	Median	(95% UVR)
4–6 years	2.2 (4.5)	1.2 (2.0)	0.2–6.0 (0.9–26.7)	2.0 (7.9)	1.2 (4.5)	0.2–3.2 (1.0–31.2)
7–9 years	1.4 (2.8)	1.4 (2.3)	0.2–2.7 (0.6–13.1)	4.0 (12.2)	2.2 (6.3)	0.2–7.2 (1.9–51.2)
13–14 years	1.6 (2.9)	1.0 (1.9)	0.1–3.7 (0.5–12.0)	3.2 (9.8)	1.2 (6.5)	0.2–5.0 (1.4–48.0)
All subjects	1.7 (3.4)	1.1 (2.1)	0.2–6.0 (0.9–26.7)	3.1 (10.1)	1.4 (6.0)	0.2–7.2 (1.5–51.2)

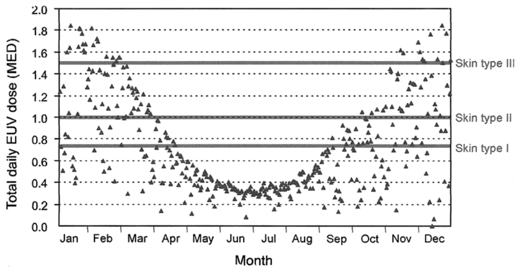

Figure 4. Potential total daily erythemal UVR dose (J·m^{-2}) that children and adolescents may receive during a typical year in Durban. The horizontal lines indicate the levels at which individuals of skin types I (150 J·m^{-2}), II (200 J·m^{-2}) and III (300 J·m^{-2}) are likely to experience minimal erythema.

measured by the YES UVB pyranometer for a typical year (in this case the year 2000). The results are displayed in Fig. 4. During summer (December–January) daily individual doses extend up to 360 J·m^{-2}, whereas during winter (June–August) values cluster around 80 J·m^{-2}. These values are considered conservative because the factor of 4.6% was an average for all 30 subjects over the study period. Individual doses varied widely, with a large percentage (50%) of PSFB doses being greater than 5% of the ambient erythemal UVR.

Overexposure to UVR is known to cause adverse health consequences, including the onset of erythema. It is generally accepted that 1 MED is the threshold above which minimal perceptible redness of the skin becomes apparent 24 h after UVR exposure (25). Dose in joules per square meter required to induce minimal, marked and painful erythema varies according to skin type, as indicated in Table 4. By superimposing these values required to induce minimal erythema on to the annual variation of an individual's total daily UVR doses, it is noted that there are 139 days during 1 year when individuals with a light skin type of type I are likely to experience minimal erythema and 97 and 32 days for individuals with types II and III, respectively. All these exceedances occurred outside the winter season, which is June–August.

CONCLUSIONS

In the light of skin cancer statistics in South Africa and the importance of early childhood UVR exposure, it was considered important to measure the UVR dose of children and adolescents. This study was conducted in the city of Durban for a 1 week period in summer for three age groups of children and adolescents (4–6 years, 6–9 years and 13–14 years). This study is believed to be the first of its kind in South Africa.

UVR-sensitive PSF was used to provide a measure of UVR dose in accordance with studies done elsewhere in England and Australia. Participants kept daily journals describing their activities, which provided some insight into the role of behavior patterns in determining UVR dose.

The mean and median PSFB doses for all ages over the study period were 2.1 and 1.2 SED units, respectively. No significant statistical differences were found between PSFB doses as a function of age, although it was noted that males generally received higher UVR doses than females.

The variability in individual PSFB doses was found to be dependent on the nature of activities in which an individual was engaged. This was reflected in the differences in PSFB doses on weekdays when compared with weekends. Most of the activities on days with highest PSFB dose were related to swimming or beach activities.

Table 4. Dose required to induce minimal, marked and painful erythema for skin types I–IV (B. L. Diffey, personal communication)

Skin type	Dose (J m^{-2})		
	Minimal erythema	Marked erythema	Painful erythema
I	150	450	750
II	200	600	1000
III	300	900	1500
IV	400	1200	2000

On average, subjects received a UVR dose of 4.6% of the ambient daily erythemal UVR. This factor was used to estimate the potential dose of an individual over the full annual cycle. This estimate assumes that the subject's outdoor behavior patterns remained relatively unchanged throughout the year. Based on the dose in joules per square meter required to induce minimal, marked and painful erythema for different skin types as suggested by B. L. Diffey (personal communication), it was estimated that there are 139 days in a typical year when individuals with skin type I are likely to experience minimal erythema and 97 and 32 days for individuals with skin types II and III, respectively.

Individual UVR dose was found to be largely dependent on the activity of the individual, although it is expected that random human movement and variation in the orientation of the anatomic site toward the direct solar beam will influence the PSFB dose. Future work will focus on quantifying this relationship.

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