EFFECT OF CHILDHOOD AND ADOLESCENT ULTRAVIOLET EXPOSURES ON CUMULATIVE EXPOSURE IN SOUTH EAST QUEENSLAND SCHOOLS

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ABSTRACT

Quantitative estimates of the childhood and adolescent erythemal UV exposure received in South East Queensland schools are provided in this paper for age groups 0 to 6, 7 to 12 and 13 to 19 years. For the neck, hand and lower arm, sites of high UV exposure that are generally not covered by clothing, 13 to 19 year olds received the highest exposure of the three age groups, followed by 7 to 12 year olds. Exposure for 13 to 19 year olds contributed up to 44% of cumulative exposure to 20 years, and exposures for the 7 to 12 year olds contributed up to 31%. If the annual UV exposure for these two age groups were reduced to the average of all the age groups, cumulative erythemal UV exposure from 0 to 20 years would be reduced by up to 16%. On the other hand if mothers can protect their babies by reducing the level of annual exposure to 30% of the annual UV exposure of the 7 to 12 year olds for the first four years then cumulative exposure to UV to age 20 would be reduced by up to 19%. These data confirm the importance of targeting young age groups in public campaigns for sun protection.

INTRODUCTION

Two out of three Australians will have some form of skin cancer by the age of 75 (1). A strong latitudinal gradient of the incidence rates of non-melanoma skin cancer (NMSC) has been found, with the rates in latitudes less than 29 ^{o}S more than four times the rates in latitudes greater than 37 ^{o}S (2). Epidemiologic evidence suggests that childhood exposure to ultraviolet radiation (UV) is an important factor in the cause of skin cancer (3).

Measurement programs employing polysulphone dosimeters (4) to measure the short term erythemal UV exposure to school children have been undertaken (5-8), while Diffey *et al*. (9) measured exposure to children and adolescents over a period of three months. Whiteman *et al*. (10) have considered solar UV exposure as a risk factor for childhood melanoma in Queensland using a sun exposure calendar completed by parents and children, although high ambient UV levels in that state made it difficult to detect significant differences in exposure between melanoma cases and controls. There has been no quantitative estimation of UV exposures during childhood and adolescence based on experimental data. More detailed information on UV exposure during childhood and adolescence could assist in the formulation of guidelines for programs in the reduction of lifetime exposure and hence the risk of skin cancer and skin aging. In this paper, we estimate using experimental data erythemal UV exposure received by children and adolescents in South East Queensland schools.

MATERIALS AND METHODS

Participants

Subject selection has been described previously (11). Briefly, participants were randomly chosen from eight schools across South East Queensland and within 100 km of the Biometer (model 501, Solar Light Co., Philadelphia, USA) site, and were divided into two age groups to reflect the change in lifestyle between primary and secondary school: 7 to 12 year olds (primary school), 13 to 19 year olds (secondary school). In addition, teachers and school workers from these schools were invited to participate, to allow comparison of childhood and adolescent exposures with those of older age groups in a similar setting.

Exposure Model

Monthly erythemal UV exposures for participants were determined for a period of 12 months using a published and well-known model (12-16). These monthly data were summed to provide estimates of annual UV exposure.

The model for determining the annual exposure incorporates the four variables of the ambient erythemal UV exposure (AE) on a horizontal plane, the exposure ratio (ER) or the fraction of the ambient UV incident on a specific anatomical body site, the activity index based on the activities undertaken (FO) and the protection factor (PF). The annual erythemal UV exposure is the summation of the monthly exposures, UV(S) to a specific anatomical body site, S, defined as follows:

$$UV(S) = \sum_{W=1}^{2} \sum_{H=6:30am}^{6:30pm} \sum_{i=1}^{8} \frac{ER(i,S)x10AE(W,H)xFO(H,i)}{PF(S,H)} + \sum_{E=1}^{2} \sum_{H=6:30am}^{6:30pm} \sum_{i=1}^{8} \frac{ER(i,S)x4AE(E,H)xFO(H,i)}{PF(S,H)} \quad (1)$$

where the first term is erythemal UV exposure on the weekdays, W, the second term is the erythemal UV exposure on the weekends, E, H is the half hourly intervals and i is the number of body positions being considered for each activity.

The ambient erythemal UV exposure was measured with a Biometer permanently mounted on a horizontal unshaded plane on the roof of a building at the Queensland University of Technology, Brisbane (latitude 27.4° S), Australia. The data was recorded in units of MED/30 minutes where an MED is defined as the minimal erythemal dose required to produce barely perceptible erythema after an interval of 8 to 24 hours following UV exposure (13). The Biometer was calibrated against a calibrated spectroradiometer (17).

The exposure ratio was expressed as a number between zero and unity and was measured for seven anatomical body sites, namely: hand, lower arm, shoulder, upper leg, upper arm, neck and lower back. Ideally, exposure ratios are determined on human volunteers, however, this is neither always practical nor convenient and an established technique using manikins (18) was employed here. Manikins with movable limbs were used to simulate seven common human activities of standing, walking, running, lying, sitting, kneeling and bending. These activities were chosen due to their ability, either singularly or in combination, to represent the majority of human activities. For each stance, with the exception of lying, the manikins were placed in position and rotated by 90 degrees three times during the measurement period of approximately one hour during the middle of the day. Measurements for the activity of lying were taken with the manikin lying both face down and face up. For each activity, twelve measurements of the exposure ratios were undertaken.

The exposure ratios were measured by attaching polysulphone dosimeters (4) to each of the seven body sites. The erythemal UV exposure to each site was normalised to the erythemal UV measured over the exposure period with a polysulphone dosimeter deployed on a horizontal plane.

The activity index was determined from the activities recorded by participants in a personal daily diary (see Appendix). In the diary, the day was divided into half hourly blocks and the diary allowed for two activities per half-hour block. The body position options presented in the diaries were the seven for which the exposure ratios were calculated. The half-hour division was employed to correspond with the recording interval of the ambient erythemal UV irradiance by the Biometer. Data were collected over four days in each month:

- One weekday during the first two weeks of the month and one weekday during the second two weeks of the month;
- One weekend day during the first two weeks of the month and one weekend day during the second two weeks of the month.

Each participant was sent the four diary questionnaires for one month in each season over the period of one year, namely: September or October 1995 (spring), February 1996 (summer), May 1996 (autumn) and August 1996 (winter). The total number of participants who returned diaries for each of the four seasons was 85, 60, 37 and 40 respectively.

The protection factor is defined as the ratio of UV exposure to unprotected skin to the UV exposure to the skin when it is protected and is based upon the level of protection

afforded an individual by the various protective devices such as sunscreen, hats, clothing or shading. No attempt was made to determine the properties of the clothing worn by the participants. Instead an average protection factor was chosen for various articles of clothing based on previous research (19, 20), namely: 25, 60, 25, 60 and 60 for a shirt/blouse, jumper/jacket, dress, skirt and shorts/long pants respectively. Based on previous research, the protection factor for shade was taken as 2. The body sites covered by these protection factors were assessed by the data collected in the diary questionnaires. The use of sunscreens and hats was not recorded, thus, exposures may be overestimated to the extent that hats and sunscreen were used.

Childhood and Adolescent Exposures

Monthly erythemal UV exposures to each site were calculated using Equation (1) and from this annual exposures were estimated. Airey and colleagues (15) have estimated the standard error in estimates of UV exposures for a particular season to be approximately 35%. The annual exposure for children aged 7 to 12 years was extrapolated to provide an estimated annual exposure for the 0 to 6 years age group. Scenarios of different exposures to the 0 to 6 year olds are considered below. The cumulative UV exposures of a child born today up to the age of 20 years at each of the seven anatomical body sites were estimated as the sum of the annual exposures for all the ages up to 20 years. The estimation makes the following assumptions:

- The solar erythemal UV irradiances will not change in the next 20 years;
- The activities performed by the participants in this study will be similar to those performed by people of the same age groups for the next 20 years;
- The persons reside in South East Queensland, completing 12 years of schooling.

Reduction of the UV exposure during the 0 to 6, 7 to 12 and 13 to 19 years would of course reduce cumulative exposure to 20 years. To quantify the amount of this reduction, the cumulative erythemal UV exposures up to 20 years for six hypothetical scenarios have been considered, as follows:

- Scenario 1 - The annual erythemal UV exposures of children aged under 1 year, and aged 1, 2, 3, 4, 5, and 6 years were taken as 10%, 10%, 25%, 50%, 50%, 100% and 100% respectively of the annual UV exposures of the 7 to 12 years age group;
- Scenario 2 - The annual erythemal UV exposures for the first four years were reduced to 30% of the annual UV exposures of the 7 to 12 years age group;
- Scenario 3 - The annual erythemal UV exposures of the 7 to 12 years group were reduced to that of the average for all of the age groups;
- Scenario 4 - The annual erythemal UV exposures of the 13 to 19 years group were reduced to that of the average for all of the age groups;
- Scenario 5 - The annual erythemal UV exposures of both the 7 to 12 years and 13 to 19 years group were reduced to the average for all of the age groups;
- Scenario 6 - The annual erythemal UV exposures of the 0 to 6 years, 7 to 12 years and 13 to 19 years group were all reduced to the average for all of the age groups.

Scenarios 1 and 2 were selected to quantify the effect of reducing the UV exposures of babies and younger than school age children. Scenarios 3 to 5 were selected to determine the effect of reducing the UV exposures of the two high exposure age groups and scenario 6 was employed for the influence of reductions to all of the age groups.

RESULTS

Exposure Model

The means of the exposure ratio data to each of the seven body sites are presented in Table 1 for each of the seven activities with the error represented as the standard error of the set of measurements. The results show that the highest exposed sites vary with activity, with the neck and lower back having the highest ratios for bending and kneeling activities, and the shoulder being the most exposed site of those measured for standing, sitting, walking and running.

Childhood and Adolescent Exposures

The annual erythemal UV exposures to each of the body sites of the 7 to 12 year old and 13 to 19 year old age groups are expressed as a percentage of the ambient exposures in Table 2. For the high UV exposure site of the neck, the annual UV exposures were 144 kJ m^{-2} and 163 kJ m^{-2} for the 7 to 12 years and 13 to 19 years respectively.

The cumulative erythemal exposures up to an age of 20 years are provided in Table 3. The body sites with the highest exposures by approximately a factor of 10 are the neck, hand and lower arm. The lower arm received a higher exposure than the shoulder due to the protection provided to the shoulder by clothing. The final two columns in Table 3 show the percentage contribution of the erythemal UV exposures for the 7 to 12 years and 13 to 19 years groups to the cumulative erythemal UV exposure to 20 years. The percentage contributions range from 26 to 31% for the 7 to 12 years and 34 to 44% for the 13 to 19 years.

The average annual erythemal UV exposures of all the age groups for the three sites of the neck, hand and lower arm that are generally not covered by clothing and receive the highest UV exposures are considered in Table 4. The percentage comparison of the annual exposures for the 7 to 12 and 13 to 19 years age groups compared to the average of the annual exposures for all the groups are provided in the final two columns. The annual erythemal UV exposures for the 7 to 12 years group were 19 to 35% above that of the average and for the 13 to 19 years group, they were 29 to 36% above that of the average. The cumulative childhood and adolescent erythemal UV exposures to age 20 years based on reduced UV exposures for each of the hypothetical scenarios 1 to 6 are shown in Table 5 along with the percentage reduction in cumulative UV exposures that could be achieved with a reduction in childhood and adolescent UV exposure.

DISCUSSION

Quantitative estimates of the childhood and adolescent erythemal UV exposures received in South East Queensland up to an age of 20 years have been provided in this paper. The estimates of the UV exposures have not included the use of the protective strategies of hats and sunscreens and consequently, may be overestimates. This paper has provided for the first time, quantitative estimates of the cumulative childhood and adolescent erythemal UV exposures up to age 20 years. The exposure up to age 20 years to the neck was 30.1×10^5 J m^{-2} or 15,050 MED. The upper leg was the site with the lowest exposure with 1.85×10^5 J m^{-2} or 925 MED.

For the high UV exposure sites of the neck, hand and lower arm that are generally not covered by clothing, the 13-19 year olds received the highest exposures of the age

groups followed by the 7-12 year olds. The exposure for the 13 to 19 year olds contributed up to 44% of the cumulative exposure to 20 years and the exposures for the 7 to 12 year olds contributed up to 31%. Reduction of the annual erythemal UV exposures in the first four years to 30% of the annual UV exposures of the 7 to 12 year age group provides a significant reduction of up to 19% in the erythemal UV exposures up to age 20. For the back of the neck, the reduction was 2,732 MED. Similarly, reduction of the annual UV exposures for each of the high UV exposure groups of the 13 to 19 year olds and the 7 to 12 year olds to that of the average for all the different age groups reduced the cumulative erythemal UV exposures to 20 years by up to 10% and 8% respectively. Reduction of the annual UV exposure of both groups reduced the cumulative erythemal UV exposures to 20 years by up to 16%. These data confirm the need to target younger age groups in public campaigns on UV protection, and also provide a quantitative estimate of the effect on the cumulative exposures of reductions in UV exposures in early life.

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Table 1 – Mean and standard error of the exposure ratio measurements.

Activity	Hand	Lower arm	Upper arm	Shoulder	Upper leg	Neck	Lower back
Standing	0.35±0.06	0.25±0.03	0.29±0.05	0.70±0.04	0.17±0.02	0.36±0.04	0.35±0.02
Sitting	0.44±0.05	0.47±0.06	0.34±0.05	0.63±0.03	0.52±0.03	0.36±0.04	0.35±0.02
Bending	0.52±0.07	0.42±0.07	0.36±0.05	0.55±0.06	0.21±0.04	0.76±0.04	0.85±0.04
Kneeling	0.51±0.07	0.52±0.06	0.35±0.04	0.60±0.05	0.17±0.01	0.63±0.05	0.73±0.04
Walking	0.37±0.06	0.32±0.05	0.30±0.04	0.58±0.06	0.27±0.05	0.54±0.08	0.57±0.08
Running	0.43±0.08	0.45±0.07	0.30±0.05	0.66±0.06	0.30±0.07	0.60±0.05	0.66±0.05
Lying	0.29±0.04	0.41±0.06	0.31±0.04	0.29±0.03	0.38±0.09	0.39±0.08	0.39±0.07

Table 2 – Annual erythemal UV exposures to the body sites for each age group in South East Queensland expressed as a percentage of the ambient exposures compared to those of older age groups.

Body Site	Percentage of ambient UV exposures		
	7-12 years	13-19 years	20 years and older
Neck	9.7	10.8	5.5
Hand	8.5	9.3	4.7
Lower arm	7.9	7.6	3.5
Shoulder	0.83	1.2	0.69
Lower back	0.65	0.95	0.61
Upper arm	0.74	1.0	0.36
Upper leg	0.42	0.55	0.30

Table 3 – Cumulative childhood and adolescent erythemal UV exposures up to an age of 20 years to the seven body sites and the percentage contribution of the exposure during the 7 to 12 and 13 to 19 years to this cumulative exposure.

Body Site	Erythemal UV Exposures (10^5 J m^{-2})	% exposure of 7-12 years	% exposure of 13-19 years
Neck	30.1	29	38
Hand	26.5	29	38
Lower arm	23.1	31	34
Shoulder	3.17	26	44
Lower back	2.47	26	44
Upper arm	3.06	26	44
Upper leg	1.85	30	35

Table 4 – The average annual erythemal UV exposures of all the age groups and the percentage comparison of the annual exposures for the 7 to 12 and 13 to 19 years age groups compared to the average.

Body Site	Average annual erythemal UV (10^5 J m^{-2})	Compared to average (%)	
		7-12 years	13-19 years
Neck	1.2	+19	+35
Hand	1.0	+22	+36
Lower arm	0.87	+35	+29

Table 5 – Cumulative childhood and adolescent erythemal UV exposures to age 20 years based on reduced UV exposures for each of the scenarios 1 to 6[†] and the respective percentage reductions to the cumulative erythemal UV.

Site	Cumulative Erythemal UV (10^5 J m^{-2})						Reduction to Cumulative Erythemal UV (%)					
	Scenarios						Scenarios					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Neck	25.0	24.7	28.7	27.1	25.8	24.1	17	18	5	10	15	20
Hand	22.0	21.6	25.1	23.9	22.5	20.9	17	18	5	10	15	21
Lower arm	18.9	18.6	21.2	21.3	19.5	17.4	18	19	8	8	16	25

[†]Scenario 1 – UV exposures to ages under 1 year, 1, 2, 3, 4, 5 and 6 years taken as 10%, 10%, 25%, 50%, 50%, 100% and 100% respectively; Scenario 2 – First four years exposures reduced to 30%; Scenario 3 – UV exposures of the 7 to 12 years group reduced to the average; Scenario 4 - UV exposures of the 13 to 19 years group reduced to the average; Scenario 5 - UV exposures of the 7 to 12 years and 13 to 19 years group reduced to the average; Scenario 6 - UV exposures of the 0 to 6 years, 7 to 12 years and 13 to 19 years group reduced to the average.

APPENDIX

Diary Questionnaire

Today's date: _____

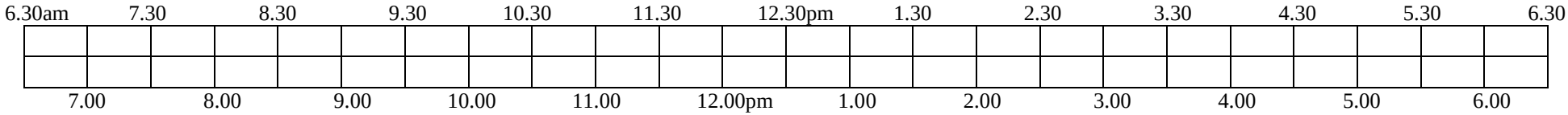
Part A: Please complete the diary below, giving a brief description of what you were doing for each half hour period. If more than one thing was done during that half hour period, please list them all. Also indicate which body position (or positions) best describes the activity you were performing by ticking a box. If an activity was performed for more than the half hour period, write "AS ABOVE" in each time period activity box.

Time	Description of Activity	Body position (please tick appropriate number of boxes for each activity)							
		Standing	Sitting	Bending	Kneeling	Walking	Running	Lying	Other (specify)
6.30am-7.00									

The above table had a row for each half hour period to 6.30 pm.

Part B: On the graph below, please indicate the times when you are outside by drawing a thick line at the appropriate time(s). If you are outside but in the shade (such as under trees or an awning of a building), please indicate this by shading the appropriate areas of the graph.

Today's date: _____



Part C: On the diagrams, please indicate the clothes you were wearing by shading in the area of the body covered by the clothes. Also include a brief description of the clothes and the time that the clothes were worn. Note that the same diagram can be used for different times of the day (if appropriate).

Today's date: _____

Description:_____
_____
Time(s):_____
_____

Description:_____
_____
Time(s):_____
_____

Description:_____
_____
Time(s):_____
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Description:_____
_____
Time(s):_____
_____

Part D: Please complete the following questions by ticking only one box, unless indicated:

1. Did you apply sunscreen when outside today? ☐ Yes ☐ No
2. Would you say this was a typical day for you at this time of year? ☐ Yes ☐ No
3. Would you normally spend more or less time in the sun than you have indicated? ☐ More ☐ About the same ☐ Less time
4. How would you describe the weather today? You may choose more than one option: ☐ Sunny ☐ Slightly cloudy ☐ Very cloudy ☐ Overcast ☐ Stormy ☐ Rain