LIFETIME ULTRAVIOLET EXPOSURE ESTIMATES FOR SELECTED POPULATION GROUPS IN SOUTH EAST QUEENSLAND

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ABSTRACT

The lifetime erythemal UV exposures received by selected population groups in South East Queensland from birth up to an age of 55 years have been quantitatively estimated. A representative sample of teachers and other school workers received $(64\pm22)x10^5$ *J* m^{-2} *to the neck compared to* $(4.1\pm1.4)\ x10^5$ *J* m^{-2} *to the upper leg. A sample of indoor workers (bank officers, solicitors and psychologists) received approximately 2% less and a sample of outdoor workers (carpenters, tilers, electricians and labourers) received approximately 10% more to the neck than the school workers. These differences in erythemal UV exposures may influence the risk of non- melanoma skin cancer.*

Keywords: ultraviolet, erythema, dosimetry, non-ionizing, skin cancer

1. INTRODUCTION

The risk of non-melanoma skin cancer (NMSC) is associated with exposure to ultraviolet (UV) radiation (Longstreth et al., 1995, Kricker et al., 1995). Human exposure to ultraviolet radiation has been previously measured over relatively short periods using polysulphone dosimeters in a variety of environmental settings for both occupational and recreational activities (Diffey et al., 1996, Rosenthal et al., 1988, 1990, 1991, Leach et al., 1978, Melville et al., 1991, Challoner et al., 1976, Gies et al., 1995, 1998, Holman et al., 1983, Kimlin et al., 1998a, 1998b, Herlihy et al., 1994).

Diffey (1992) has used a model proposed by Rosenthal et al. (1991) for estimating longterm exposures based on published data obtained in the United Kingdom. The model was extended by Airey et al. (1997) and Wong et al. (1996) to estimate long-term exposures to solar UV radiation in the Australian environment for periods of a season and a year respectively, using Australian data on exposure ratio and ambient radiation. There are no published estimates of lifetime erythemal UV exposure based on experimental data. In this paper we quantitatively estimate the exposure to solar UV radiation received in South East Queensland, Australia by selected groups of indoor and outdoor workers, and use these to estimate projected lifetime UV exposure from birth up to an age of 55 years for various occupational groups under a range of assumptions.

2. MATERIALS AND METHODS

2.1 Participants

A total of 220 randomly selected students from 4 primary schools and 4 secondary schools within a 100 km radius of the Biometer (see below) site were included in the study. Differences in local ambient UV exposures are considered to average less than 10% over this area (Gies et al., 1995).

In addition, participants included a convenience sample of 20 indoor workers in South East Queensland, including bank officers, solicitors and psychologists; and 10 outdoor construction workers in South East Queensland, including carpenters, tilers, electricians, and labourers. School staff's occupational exposure to UV may vary from low (librarians) to high (physical education teachers). As a result, the group of school workers in this sample was hypothesised to have UV exposures intermediate between the indoor and outdoor worker groups.

2.2 Data Collection

To estimate the number of hours of daily UV exposure by participants on weekdays and weekends, the clothing worn, activities, and body posture in each season, students and school workers completed diary questionnaires during one month in each season over a 12 month period, namely: September or October 1995 (spring), February 1996 (summer), May 1996 (autumn), and August 1996 (winter). To allow both recreational and occupational exposure to be studied, diaries were completed on four days during each of the four months: one weekday and one weekend day during the first half of the month and one weekday and one weekend day during the second half of the month (Diffey, 1992). Increasing the number of periods in the month was not justified, considering the limited increase in precision that this would have provided.

In the questionnaire, the day was split into half-hourly intervals between 6.30 am and 6.30 pm. For each half-hour period spent outdoors, the participant was asked to describe the activity, body position and clothing worn. Among the total of 220 over the four seasons of participating students and school staff, 85, 60, 35 and 40 four-day diaries were completed in spring, summer, autumn and winter respectively. In addition, 20 four-day diaries were completed by the indoor workers and 10 by the outdoor workers during spring 1996.

2.3 Estimation of UV Exposure

The erythemal UV exposure, UV_{ery} over an exposure period, T, is defined as:

$$UV_{ery} = T\int_{UV} S(\lambda)A(\lambda)d\lambda \qquad (1)$$

where S(λ) is the source solar spectrum, A(λ) is the erythemal action spectrum (CIE, 1987) and the integration is over the UV waveband.

Monthly erythemal UV exposures for each group were estimated for selected body sites employing an exposure model previously described (Rosenthal et al., 1991, Diffey, 1992, Wong et al., 1996, Airey et al., 1997). Weekday and weekend exposures were estimated separately. UV exposures were estimated for the hand, lower arm, shoulder, upper leg, neck and lower back. Monthly exposures for each site were summed to provide an estimated annual UV exposure (Wong et al., 1996) for that site. The errors for all the values provided in the tables in the results were estimated based on the experimental results obtained from this project and those reported by our group in another publication (Airey et al., 1997).

The model incorporates the following four variables: (i) ambient erythemal UV exposure to a horizontal plane, (ii) the exposure ratio, that is, the fraction of the ambient UV incident on the specific body site compared to that on a horizontal plane, (iii) the activity index based on the activities undertaken during sunlight hours as recorded in the diaries and (iv) the protection factor. Ambient erythemal UV irradiances were measured using a Biometer (model 501, Solar Light Co., Philadelphia, USA) 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 Biometer stored the erythemal UV exposure for each half-hourly interval of the day and was calibrated employing Equation (1) against a spectroradiometer (Wong et al., 1995) with calibration traceable to the UV standard lamp at the CSIRO National Measurement Laboratory.

The exposure ratio is a ratio between zero and unity and was measured for the seven body sites of neck, shoulder, upper arm, lower arm, hand, lower back and upper leg, as described elsewhere (Wong et al., 1996). Briefly, this involved placing polysulphone dosimeters on each of these body sites on manikins in each of the common human postures for standing, walking, running, lying, sitting, kneeling and bending. The polysulphone was calibrated by exposing to different erythemal UV exposures and measuring the resultant change in optical absorbance at 330 nm of the polysulphone dosimeters in a spectrophotometer (model Ultrospec II, Pharmacia LKB Biochrom Ltd). For the manikins, twelve measurements were taken at each body site in each posture. The activity index was calculated as described elsewhere using information from the daily diaries in which were recorded activities conducted in each half-hourly block during the day (Wong et al., 1996).

The protection factor is defined as the ratio of the UV exposure to unprotected skin compared to the UV exposure to the skin when it is protected. Average protection factors for various articles of clothing have been determined as 25, 60, 25, 60 and 60 for a shirt/blouse, jumper/jacket, dress, skirt and shorts/long pants respectively (Welsh and Diffey, 1981, Gies et al., 1992). Shade was assigned a protection factor of 2 (Airey et al., 1997). The use of sunscreens and hats was not included in the model, and if these were used by participants, their exposures may be somewhat overestimated.

2.4 Lifetime Exposure

Participants were divided into the age groups of: 7-12 years (primary school), 13-19 years (secondary school), 20-29 years, 30-39 years, 40-49 years and 50-59 years. The division between primary and secondary school was selected to reflect the change in lifestyle between the two levels of schooling. For the 20 years and older age groups, the division by decade was selected as any more division would not necessarily provide any greater accuracy to the data. Lifetime exposures for each body site were estimated by summing annual UV exposures for all age groups up to 55 years (Meldrum, 1998). The annual exposures for children aged 0 to 6 years were assumed to be the same as the 7 to 12 year’s age group. The estimation of the lifetime erythemal UV exposures assumes that ambient UV irradiances remain constant over the period.

In the absence of four-day diaries for summer, autumn and winter for indoor and outdoor workers, their annual exposure was estimated by considering the percentage difference in total spring ambient exposure for each site for indoor workers compared to school workers, and for outdoor workers compared to school workers, and applying this percentage difference to the other seasons for each group. This estimation is based on the assumption that the school, indoor and outdoor workers maintain consistent differences in exposure throughout the year.

Lifetime exposures were estimated for various hypothetical situations, in all cases, assuming that people remain at school until year 12:

- A person who works to age 55 years as a school worker;
- A person who works to age 55 years as an indoor worker;
- A person who works to age 55 years as an outdoor worker;
- A person who works as a labourer in their 20's, returns to full time study at 30 and at 35 years begins an indoor office job and continues there until retiring at 55;
- A person who is a school worker until the age of 35 and then an indoor worker to age 55 years. This may reflect the situation when a person moves to a more responsible management position as they progress through their career;
- An outdoor worker until the age of 35 years, then a school worker to 55 years. This simulates an outdoor worker moving into a job with greater responsibility as they progress through their career. However, due to the nature of outdoor occupations, a higher position would still involve some outdoor work. Consequently, an exposure the same as a school worker is employed and not an indoor worker.

3. RESULTS

3.1 Indoor and Outdoor Workers

The percentages of the total spring ambient erythemal UV exposure received to each body site for the indoor and outdoor workers compared to the school workers are provided in Table 1. For the neck, hand and lower arm, sites that are normally exposed, the percentage of the total spring ambient erythemal UV exposure for the outdoor workers was approximately 19%, 15% and 10% more respectively than that for the school workers. In spring the outdoor worker received approximately three times the percentage of the ambient UV compared to the school worker. In comparison, the same sites of the indoor workers received approximately 4%, 3% and 3% less respectively of the total spring ambient erythemal UV than the school workers. There is a large variability in exposure between individuals in a homogeneous group. The standard error is presented in Table 1.

Although the exposure of school workers was intermediate between indoor and outdoor workers for the majority of the sites, as would be expected, there were lower percentage differences in exposure between the worker groups for less habitually exposed sites such as the lower back and upper leg. For the upper leg, the percentage of the ambient exposure for the outdoor workers is less than that for the school workers. This may be due to the higher average protection factor of 60 for the shorts/long pants that would be predominantly worn by outdoor workers compared to the articles of clothing worn by school workers, namely dress, skirt and shorts/long pants with average protection factors of 25, 60 and 60 respectively.

3.2 Lifetime Exposure

The lifetime erythemal UV exposures to an age of 55 years are presented in Table 2 for the three worker groups. For the indoor and outdoor workers lifetime exposures, the difference in the percent of the ambient spring exposure was added or subtracted in each of the other seasons for each of the age groups above 20 years to obtain the indoor and outdoor workers exposures. For example, for the neck site, the outdoor workers received approximately 19% more of the ambient spring exposure from Table 1. For each of the age groups above 20 years, the outdoor workers exposure was calculated by increasing the school workers exposure by 19%. Consistently, for all groups, the body sites that received the greatest exposure were the neck, hand and lower arm, with the upper arm and upper leg receiving the least exposure. For all sites, the outdoor workers received the highest UV exposures, and indoor workers the lowest, with school workers intermediate between the two. For the higher UV exposure sites of the neck, hand and lower arm, the outdoor workers received 6×10^5, 4×10^5 and 2×10^5 J m^{-2} respectively more than the school workers. Respectively, these are 3,000, 2,000 and 1,000 MED, where the unit of MED is defined as the minimum erythemal dose required to produce barely perceptible erythema after an interval of 8 to 24 hours following UV exposure (Diffey, 1992) and is taken as 200 J m^{-2} in this research. In comparison, the outdoor workers received 8×10^5, 5×10^5 and 2×10^5 J m^{-2} or 4,000, 2,500 and 1,000 MED more than the indoor workers to the neck, hand and lower arm respectively. While differences were consistent, none were statistically significant.

The lifetime erythemal UV exposures for the three situations involving changes in occupation are provided in Table 3. These indicate that a change from an outdoor to a more indoor occupation at any point in a working career will bring an accompanying reduction in lifetime UV exposure at all measured sites, and particularly for the neck, hand, and lower arm. Estimated lifetime exposures for all three hypothetical situations are lower for the high exposure sites of the neck, hand and lower arm than those for the outdoor worker group (Table 2), although no differences are statistically significant.

4. DISCUSSION

This paper provides experimental estimates of the lifetime erythemal UV exposure received by selected population groups in South East Queensland from birth up to an age of 55 years. Consistently, the most exposed sites are the neck, hand, and lower arm, with the upper arm and upper leg receiving the lowest exposures of the sites measured. Outdoor occupations including tradesmen and construction workers received higher exposure at all sites than office workers, with school workers intermediate between the two.

These estimates of the lifetime UV exposures to age 55 years do not take account of protective strategies such as the use of hats and sunscreens, consequently exposure may be somewhat overestimated. The estimates assume that the ambient erythemal UV irradiances will not change significantly in South East Queensland over the next 55 years; activities of the participants in this research are similar to people of the same age groups for the next 55 years; the annual UV exposure of the 0 to 6 years age group is similar to the 7 to 12 years age group; and the population group continues to reside in South East Queensland and completes 12 years of education.

Comparison of the lifetime UV exposures determined in this research with the estimates by Diffey (1992) of the lifetime facial exposure received by an indoor worker in the United Kingdom emphasises the much higher solar UV irradiances in South East Queensland. For example, Diffey (1992) estimated that a child currently aged 10 would receive a lifetime facial exposure of 13.5×10^5 J m^{-2} at the age of 60. This is less than a third of the UV exposure received on the lower arm of an indoor worker in this study, and less than a quarter of the UV exposure to their neck.

The method we have employed provides for the first time experimental estimates of lifetime UV exposure in South East Queensland for selected occupation groups. The sample is small, and confidence intervals are wide, however, the method appears to provide estimates that are internally consistent, and may be useful in estimating lifetime UV exposure for aetiologic studies of skin cancer in Queensland.

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Table 1. The percentage (and standard errors) of the total spring ambient erythemal UV exposure of the indoor workers, participants and outdoor workers.

Body site	Percentage of total spring ambient exposure (%)		
	Indoor Workers	School Workers	Outdoor Workers
Neck	5.4±1.9	10±3	28±10
Hand	4.6±1.6	8±3	23±8
Lower arm	2.8±1.0	6±2	16±5
Shoulder	0.43±0.15	1.1±0.4	4.3±1.5
Lower back	0.34±0.12	0.9±0.3	3.8±1.3
Upper arm	0.25±0.09	0.6±0.2	4.3±1.5
Upper leg	0.15±0.05	0.51±0.18	0.35±0.12

Table 2. Lifetime erythemal UV exposures (and standard errors) to age 55 years for three worker groups.

Body site	Lifetime UV Exposure at age 55 years (10^5 J m^{-2})		
	School Workers	Indoor Workers	Outdoor Workers
Neck	64±22	62±22	70±24
Hand	55±19	54±19	59±21
Lower arm	45±16	45±16	47±17
Shoulder	7.4±2.6	7.4±2.6	7.5±2.6
Lower back	6.0±2.0	6.0±2.0	6.1±2.1
Upper arm	5.9±2.0	5.9±2.0	6.0±2.1
Upper leg	4.1±1.4	4.1±1.4	4.1±1.4

Table 3. Lifetime erythemal UV exposures (and standard errors) to age 55 years due to change in occupations.

Body site	Lifetime UV Exposure at age 55 years (10^5 J m^{-2})		
	Outdoor Worker – Study - Indoor Worker	School Worker – Indoor Worker	Outdoor Worker – School Worker
Neck	65±23	62±22	66±23
Hand	57±20	54±19	57±20
Lower arm	46±16	45±16	46±16
Shoulder	7.8±2.7	7.4±2.6	7.4±2.6
Lower back	6.3±2.2	6.0±2.0	6.0±2.0
Upper arm	6.4±2.2	5.9±2.0	5.9±2.0
Upper leg	4.2±1.5	4.1±1.4	4.1±1.4