Photochemistry and Photobiology, 2007, 83: 749–758

Solar UVR Exposure, Concurrent Activities and Sun-Protective Practices Among Primary Schoolchildren

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Received 22 August 2006; accepted 7 December 2006; published online 18 December 2006; DOI: 10.1562/2006-08-22-RA-1010

ABSTRACT

Comprehensive measures of ultraviolet radiation (UVR) exposure, concurrent activities and sun-protective practices are needed to develop and evaluate skin cancer prevention and sun protection interventions. The UVR exposures of 345 primary schoolchildren at 23 schools around New Zealand were measured using electronic UVR monitors for 1-week periods over 12 weeks in 2004 and 2005. In addition, ambient UVR levels on a horizontal surface were measured on-site at each school. Children completed activity diaries during the period UVR measurements were made and provided information on their indoor and outdoor status and clothing and sun protection worn. Mean total daily UVR exposure (7:00–20:00 h NZST + 1) at the body location where the UVR monitors were worn was 0.9 SED (standard erythemal dose, 1 SED = 100 J m^{-2}). This was 4.9% of the ambient UVR on a horizontal surface. Mean time spent outdoors was 2.3 h day^{-1}. Differences in children's UVR exposure could be explained in part by activity, where outdoor passive pursuits were associated with higher UVR exposure rates than outdoor active and outdoor travel pursuits. Compared with older children, the activities of younger children, although labeled the same, resulted in different UVR exposures, either as a result of reporting differences or a real difference in UVR exposure patterns. UVR exposure rates were generally higher on weekdays compared with the weekend, confirming the important role of school sun protection and skin cancer prevention programs. High UVR exposure activities included physical education, athletics and lunch break.

INTRODUCTION

Relative to Europe, summer ambient solar ultraviolet radiation (UVR) reaches high levels in New Zealand (NZ), due mainly to higher solar elevations, lower ozone values (1), cleaner air, and closer proximity to the sun in the Southern summer (2). Erythemal (*i.e.* sun burning) solar noon UVR intensities are extreme at northernmost NZ latitudes during summer, *e.g.* an ultraviolet index (UVI) value of 12 or more (where 1 UVI = 2.5 μW cm^{-2} erythemally-effective UV irradiance [3]) at Kaitaia (35°S, 173°E) in January, compared with low winter values at southern latitudes, *e.g.* a UVI of 1 or less at Invercargill (46°S, 168°E) in July (4).

New Zealand annual melanoma mortality rates were the highest in the world in 2000 at 6.1 and 3.3 per 100 000, respectively, for males and females, compared with Australia (4.4 and 2.2) and the United States (2.4 and 1.2) (http://www-dep.iarc.fr/). It is estimated that more than 90% of skin cancers are caused by excess erythemal UVR exposure in high UVR environments (5,6). Other risk factors, common to both melanoma and nonmelanoma skin cancer include red and blonde hair, blue or green eye color, fair skin color, nevi and a family history of skin cancer (7–9). Of all risk factors, UVR exposure, alone, is readily modifiable.

Ultraviolet radiation exposure during childhood is considered to be important in inducing subsequent melanoma (5,10,11). Accordingly, children are identified as a key target group for sun protection and skin cancer prevention interventions (12). Other reasons include that possible changes in the skin activated during childhood increase skin cancer susceptibility and life-time skin cancer risk (13); most children attend school, which is a useful venue for dissemination of health promotion information (12), and children have greater opportunities than most adults to spend potentially large proportions of time outdoors (14), although this age-related difference may have declined (15).

Approximately 30 studies have either measured or assessed UVR exposure among children and adolescents (16). Although comparisons are difficult because of differences in study design, total daily UVR exposure as a percentage of the total daily ambient UVR during summer tends to lie within a range from 4.6% in South Africa (17), 5–6% in England (18), and up to 7% in Australia (19). However, to guide the design and targeting of preventive strategies there is limited value in knowing total daily UVR exposure, whereas real-time exposure patterns linked to concurrent activities provide more useful information (16). To date, only one study has reported UVR exposures, including among children, for high risk activities. However, the definition of "at-risk" (being at the beach and sunbathing) (20) was limited. Previous studies have

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shown that children are not a homogeneous group; there is wide variability around the group means for UVR exposures experienced by otherwise similar groups of children (18–20).

There have been numerous child-focused sun protection and skin cancer prevention programs (21–24), especially in Australia (25–27), and although one study found short-term behavioral changes (28), an improved ability to quantify and describe the characteristics of such change would be useful. For future planning and evaluation of skin cancer prevention and sun protection interventions, comprehensive measures of UVR exposure, concurrent activities and sun-protective practices are needed (29).

The goal of the study reported here was to measure the UVR exposure of NZ primary schoolchildren, both during school days and at the weekend, using objective, real-time, personal UVR monitors, and to analyze these measurements in a behavioral context through self-reported concurrent activities and sun-protective practices. On the basis of the reviewed literature it was hypothesized that UVR exposure would be related to sex, school year level (as a proxy for age) and day of the week (weekday *versus* weekend). The range in UVR exposures found among similar age groups under comparable ambient UVR conditions identified from previous studies (18–20) was considered likely to reflect differing behaviors and activities. Therefore it was further hypothesized that UVR exposure would be related to concurrent activities. The aim was to identify specific activities, associated with high UVR exposures, that are potentially modifiable—information which would be useful for informing the design and targeting of appropriate sun-protective messages towards at-risk subgroups.

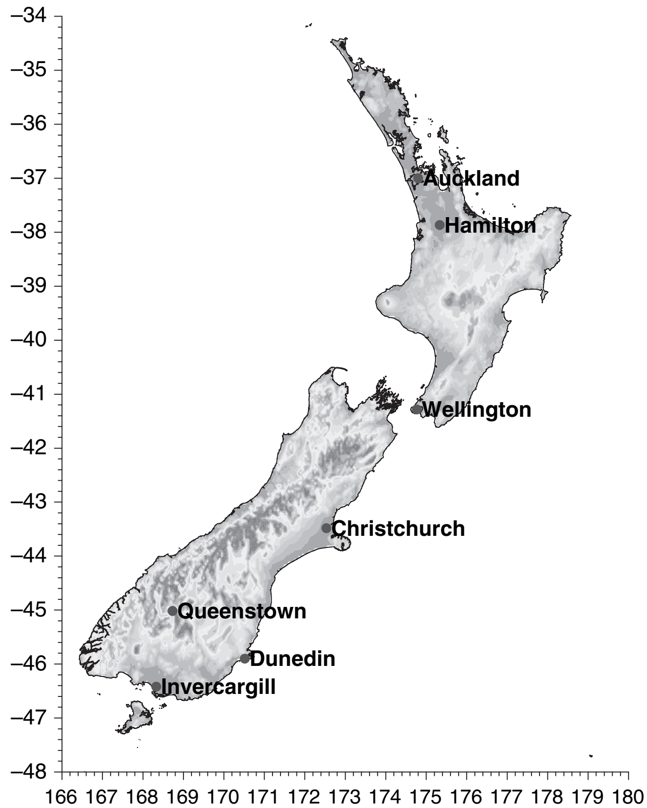

Figure 1. Map showing the seven major cities in New Zealand included in the study sample.

MATERIALS AND METHODS

Study location and subjects. Five geographical regions of NZ were selected for the study locations. Figure 1 indicates the seven major cities located within these five regions and included in the sample. The three North Island regions included Auckland and Manukau cities; Hamilton and the Waikato area; and Wellington, including Hutt and Porirua cities. The two South Island regions were Christchurch, including the Selwyn and Waimakariri districts; and Dunedin, and the large rural areas of Central Otago, including Queenstown, and Southland, including Invercargill. These were chosen from a possible total of 15 identified major regions because they provided sufficient rural-urban differences and had been used similarly in earlier studies (30,31). Six schools, State or State-integrated (previously private schools, State-integrated schools teach the NZ Curriculum but keep their own special character) (32), were randomly selected from each region using the NZ Ministry of Education schools database updated in April 2004. Two year levels, year level 4 (Y4, modal age 8 years) and year level 8 (Y8, modal age 12 years) (32), were included based on similar studies in England (18) and Australia (19) and known psychological and behavioral differences between preadolescents and young adolescents (33). Three schools from each region were randomly selected for each year level. One class, either Y4 or Y8, was randomly selected from each school. Two study periods for school visits were identified, 9 November–9 December 2004 and 1 February–13 April 2005, within the two school terms during which highest ambient UVR levels occur, and avoiding the Christmas and New Year holidays. The fieldwork began at two of the northernmost South Island schools sampled, worked southward, then shifted to the northernmost North Island schools and worked southward, ending at the top of the South Island (see Table 1). Each school was visited for 1 week. Between school visits, 1 day was allocated to allow travel between schools, thus staggering the day of the week on which the study started in each school.

Personal UVR monitor, calibration and dose–response curve. Personal erythemal UVR exposure (290–400 nm weighted with the erythemal action response) (34,35) was measured using purpose-designed personal UVR monitors. These monitors were miniaturized, lithium battery-powered UVR detectors with on-board data-logging capabilities and a clock. They have several advantages over polysulfone film (a thermoplastic that degrades when exposed to UVR, used in other studies to measure UVR exposure) because they are re-useable, their response is linear rather than logarithmic and they do not saturate (36). They also have advantages compared with other electronic and digital dosimeters (20,37), having a higher data sampling rate and storing second-by-second, nonintegrated UV irradiances which are necessary to quantify changes in UVR exposure during specific activities. The onboard data-logger logs a time-stamped measurement every 8 s and stores these measurements in EEPROM memory until downloaded to a personal computer. The UVR monitor comprises a Schottky AlGaN (Al 26%) photodiode and is encased in a shaped, waterproof polytetrafluoroethylene (PTFE) case. The AlGaN photodiode spectral response closely matches the erythemal action spectrum (35) and the shaped PTFE case provides a good cosine response (38). The UVR monitor was designed to be pinned as a lapel badge, a site known to provide a good approximation of the UVR exposure received by the hands (39). The UVR monitor was programmed to record from 7:00 to 20:00 h each day. All times were NZST + 1 as most of the study took place during daylight-saving months, October to mid-March.

By using the sun as a source on 10 consecutive days in January 2005 (mid-summer), the UVR monitors were calibrated against a second-generation "Robertson-Berger" meter model UVB-1 manufactured by Yankee Environmental Systems (YES) and maintained by the National Institute of Water and Atmospheric Research (NIWA) at Lauder, NZ. Calibration coefficients, individual to each UVR monitor, were calculated by fitting a quadratic function to erythemal irradiances measured by the Robertson-Berger meter plotted against UVR monitor output (unitless counts) (see Fig. 2). The resultant three coefficients from each calibration curve were then used to convert logged UVR monitor counts to erythemal UV irradiances over the

Table 1. Daily ambient UVR, temperature and humidity by region (range in parentheses).

Region	School	Date visited	Mean total daily ambient UVR (SED)	Mean temp. (°C)	Mean humidity (%)
Otago/Southland	1	9–15 November 2004	37.7 (20.1–56.2)	18.3 (12.8–23.9)	56 (44–69)
	2	9–15 November 2004	38.8 (16.0–50.0)	17.8 (11.9–25.0)	53 (38–72)
	3	17–23 November 2004	20.5 (12.7–33.6)	17.2 (11.9–23.9)	53 (27–88)
	4	17–23 November 2004	31.9 (12.3–59.0)	14.4 (9.0–22.4)	55 (38–72)
Auckland	5	25 November–2 December 2004	35.0 (27.0–51.0)	16.7 (12.1–20.9)	60 (44–70)
	6	25 November–2 December 2004	36.4 (22.5–50.4)	18.2 (13.9–23.3)	55 (32–81)
	7	3–9 December 2004	42.5 (16.4–65.0)	19.2 (14.1–22.9)	57 (40–73)
	8	3–9 December 2004	39.7 (19.3–58.9)	19.0 (15.0–22.1)	54 (40–68)
	9	1–6 February 2005	42.8 (30.3–67.6)	26.0 (21.0–30.3)	70 (56–87)
	10	1–6 February 2005	34.9 (7.4–49.9)	27.7 (24.4–31.8)	59 (50–69)
Waikato	11	8–14 February 2005	44.7 (34.9–53.4)	25.0 (20.9–30.0)	61 (46–81)
	12	8–14 February 2005	48.8 (27.9–61.1)	26.3 (20.0–34.4)	55 (41–72)
	13	16–22 February 2005	41.7 (21.8–46.7)	23.9 (18.4–30.8)	53 (40–75)
	14	16–22 February 2005	41.4 (14.2–55.9)	24.2 (17.9–30.3)	58 (49–67)
	15	24 February–2 March 2005	35.2 (25.2–45.6)	21.7 (10.5–31.4)	52 (36–80)
Wellington/Hutt	16	7–13 March 2005	28.8 (27.7–30.5)	18.7 (17.4–17.1)	55 (46–71)
	17	7–13 March 2005	27.7 (14.3–38.3)	19.6 (10.1–28.6)	51 (31–65)
	18	15–21 March 2005	28.6 (14.9–38.9)	19.7 (16.3–23.9)	70 (52–84)
	19	15–21 March 2005	19.4 (12.4–31.0)	20.9 (17.1–24.3)	67 (52–93)
	20	30 March–5 April 2005	12.6 (4.4–20.7)	17.3 (12.1–22.4)	67 (40–88)
	21	30 March–5 April 2005	13.7 (7.9–17.2)	17.6 (14.0–28.5)	65 (31–80)
Canterbury	22	7–13 April 2005	13.4 (6.5–18.5)	13.9 (10.4–17.5)	60 (43–85)
	23	7–13 April 2005	15.2 (6.4–21.3)	17.3 (12.3–22.9)	53 (36–78)

Note: 1 SED = 100 J m^{-2}. Instrument measuring humidity did not provide any decimal places.

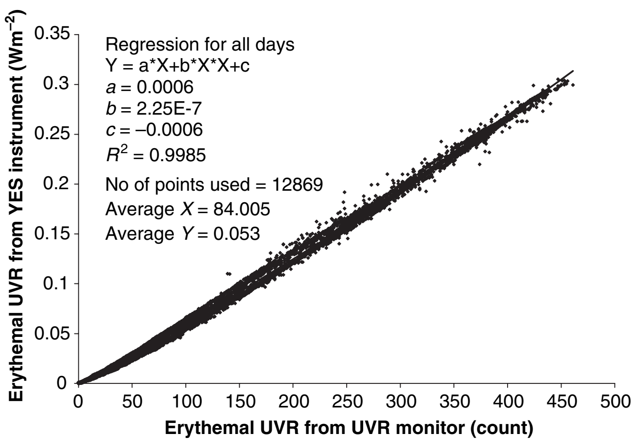

Figure 2. The dose–response curve for one UVR monitor (counts) and the YES instrument (W m^{-2} erythemally-effective UVR).

study period. This calibration was repeated in April 2005 so that drift in UVR monitor calibration over the study period, found to be very small, could be accounted for. Preliminary analyses showed that the UVR monitor was temperature-independent (any change in UVR intensity was less than 0.3% per °C) (38) and not dependent on ozone. Evidence presented in Chow *et al.* (35), as well as the linearity (high R^2 value) of the calibration over a wide range of solar zenith angles and ozone amounts shown in Fig. 2, confirms that the UVR monitor faithfully reproduces erythemal irradiances from more traditional instruments.

Procedures for personal UVR monitor usage. Ethical approval for this project was provided by the University of Otago Human Ethics Committee (Ref. No. 04/028). Prior to starting at each school, parents or guardians of the children gave informed written consent. Children were issued with a personal UVR monitor and instructed to attach it to the lapel of the outer layer of clothing from "the time they woke up until the time that they went to sleep at night." The children were able to go swimming with the UVR monitor in a swimming pool and boys were asked to pin the badge to the waistband of their swimming shorts. Monitor detachability was a concern and children were asked not to wear the badge in murky, moving or very deep water environments, *e.g.* the ocean, a pond or a lake, where it would be difficult to retrieve a detached monitor. Instead, they were asked to place the UVR monitor on an exposed, flat surface with the sensor facing upwards. On the few such occasions when children did need to remove the UVR monitor under these conditions, the UVR exposure during that activity would be overestimated as it is known that water reduces UVR exposure. However, this methodology was used in a previous study (20), and because swimming mostly took place in swimming pools and rarely in the ocean, ponds or lakes, the contribution of excess exposure to UVR exposure was expected to be small and no correction was made for this.

On-site ambient UVR measurements. One UVR monitor was used as a control at each school to measure on-site ambient UVR. This monitor was placed on the roof of a school building in a horizontal, un-shaded location for the 1-week study period at that school.

Concurrent outdoor activity patterns and sun-protective practices. Each child was asked to complete a 7-day activity diary, with one page per day, divided into 10-min intervals, and columns for activities, indoor or outdoor status, sun protection and clothing worn. Although activities were logged at 10-min intervals throughout the day, diary design only required start and end times for activities specified to the nearest 10 min. Each activity, irrespective of length, required a single line entry incorporating tick boxes for the child to indicate whether they were indoors, inside a vehicle, outside in the sun or shade, and the sun protection used, *i.e.* wearing sunscreen, a hat or other clothing (short or long-sleeved shirt; shorts or long pants, or a short or long skirt; swimming togs). Graphics were used, linked to a key, to reduce reading and writing time. Activity entry followed a free format which allowed children to respond in their own words and provided greater opportunities for subsequent recoding and analysis. The activity diary was stored in a bag that could be hung over the shoulder and allowed diary entries to be easily made throughout the day, rather than retrospectively at the end of each day. A researcher was on site each weekday morning for a few minutes to remind participants to wear their UVR monitor and to assist with diary entries. To reduce the risk of influencing behavior and to minimize any Hawthorne effect, *i.e.* a distortion of research results caused by the response of subjects to the special attention they receive from researchers (40), the researchers did not explicitly observe nor interact with the children. Teachers and parents or guardians were asked to encourage children to wear their UVR monitors and maintain their activity diaries (especially on weekend days in the case of parents).

Sun protection coverage score. A crude sun protection coverage score was calculated for each child for each activity reported. This scoring system was based on the St John's Ambulance "Rule of Nines" which provides an approximation to the area of skin burnt on a burn victim by dividing the body into units of surface area divisible by nine, excluding the torso (41). The head and each arm are 9%, respectively, each leg is 18% and the torso is 37% (36%, plus 1% for the perineum) of the body. Adaptations of this rule have been used to score sun protection among adolescents at the beach (42) and young children playing cricket (43). This rule is reasonably accurate for preadolescents, adolescents and adults, but may not be accurate for children less than 5 years of age due to the relative disproportion of body part surface area. Clothing and sun protection items were weighted according to the body coverage provided, as follows: hat 4.5%, short-sleeve shirt 46%, long-sleeve shirt 55%, shorts 18%, trousers 36%, girl's swimming costume 37%, boy's swimming trunks 18% and sunglasses 1%. Sunscreen was weighted as 50% coverage of the remaining exposed body parts once other sun protection items were deducted. The reason for only "awarding" 50% coverage for sunscreen was known problems with the actual quantity of sunscreen applied, application and re-application (44–46). So, if a child wore a hat, short-sleeve shirt, shorts and sunscreen on the remaining exposed areas, their sun protection score was $4.5 + 46 + 18 + (4.5 + 9 + 18)/2 = 84.25\%$. Where items overlapped on the skin, for example, wearing a short-sleeve and long-sleeve shirt, or a hat and sunglasses, the score for the item providing the most coverage was used, even though layering has the potential to provide additional protection. Information on the type of garment fabric was not included in this study so as not to overburden children with the study tasks.

Data analyzed. Ultraviolet radiation exposures were calculated in two ways—as total daily UVR exposure, between 7:00 and 20:00 h (NZST + 1); and by activity, between 7:00 and 18:00 h (NZST + 1), using self-reported start and stop times recorded in the activity diary. UVR monitor-specific calibration coefficients were used to calculate UVR exposures by unique identifiers that linked each child to the UVR monitor worn, activity diary completed and UVR monitor that measured school ambient UVR. UVR exposures and ambient UVR levels are described in standard erythemal dose (SED) units, as recommended for expressing UVR exposure (47), where 1 SED = 100 J m^{-2} normalized to 298 nm according to the International Commission on Illumination erythemal action spectrum (37). UVR exposure rates are described in mSED min^{-1}, where 1 mSED min^{-1} is equivalent to 0.001 SED min^{-1} or 0.1 J m^{-2} min^{-1}. The percentage of total daily and outdoor UVR exposure received between 11:00 and 16:00 h (NZST + 1) were also calculated. This is the time period during which the Cancer Society of NZ recommends a reduction in sun exposure during daylight-saving months (October to mid-March, inclusive). Activity diary data were entered verbatim into a computer using software designed specifically for the study. Activities were grouped into seven high-level categories—indoor, in a vehicle, outdoor active (*e.g.* athletics, rugby, kayaking, soccer), outdoor passive (*e.g.* lunch, morning tea, sitting, sunbathing), outdoor travel (*e.g.* walking or cycling home), outdoors in the shade and outdoor unclassified where, for example, a place (*e.g.* outside, school, lake) rather than an activity had been described. UVR exposure rates (irradiances) were calculated for each activity by dividing the total UVR exposure for that activity by activity duration.

Statistical analyses. All analyses were carried out using SAS 9.1.2 (SAS Institute, Inc., Cary, NC). As children's attitudes and behaviors may be influenced by their peers, differences were assessed between school year levels rather than age groups. Differences in outdoor UVR exposures were modeled using a mixed model, with school year level, sex and day of the week, *i.e.* either weekday (Monday to Friday, inclusive) or weekend (Saturday and Sunday). Year level-by-sex, activity, activity-by-sex, and activity-by-year level effects were included, as well as with a random school effect to account for clustering within schools. Denominator degrees of freedom were determined using the Kenward-Rogers method (48).

RESULTS

Sample characteristics

Of the 30 schools contacted and invited to participate, 28 agreed, and two replacements were randomly selected and added to the sample. Due to technical difficulties, two schools were removed from the sample, and no UVR monitors were available for use at four other schools. One school declined to participate a week before the scheduled visit because of "over-commitment." Overall, 23 schools participated, representing a 77% school participation rate. Table 2 shows the sample characteristics by region and school year level. UVR exposure data were available for 360 of the 488 children eligible, but full UVR exposure and activity data were only available for 345 children (162 boys and 183 girls; 147 Y4 and 198 Y8 children), representing a 70% response rate, overall, and providing a total of 1510 person-days of assessment. If class sizes in nonparticipating schools were the same as participating classes, then the overall response rate was about 54%.

To consider the generalizability of our sample in relation to children in Y4 and Y8 nationally, we investigated an indicator: self-reported ethnicity. Self-identified Maori (the indigenous peoples of NZ) represented 22.4% of the sample, 11.8% reported Pacific Island ethnicities and 65.6% identified with NZ European and other ethnicities. There was evidence (Pearson chi-square test with 2 degrees of freedom, $P = 0.033$) that this study's sample was not representative of the ethnicities of 8- and 12-year-old children as for children

Table 2. Sample characteristics by region and school year level.

Region/center	Year level	No. schools	School deciles*	No. participants	Sampling fraction (%)
Auckland region	Y4	3	4,6,7	54	15.6
	Y8	3	1,2,10	52	15.1
Waikato region	Y4	2	2,4	35	10.1
	Y8	3	3,6,8	53	15.4
Wellington/Hutt Valley region	Y4	3	4,8,9	40	11.6
	Y8	3	4,7,10	58	16.8
Canterbury region	Y4	1	9	5	1.4
	Y8	1	7	12	3.5
Otago/Southland region	Y4	1	10	13	3.8
	Y8	3	6,7,10	23	6.7
Total		23		345	100

*School decile is a socio-economic rating system of 1 through 10 determined by the NZ Ministry of Education where a lower decile school includes a higher proportion of students drawn from disadvantaged families.

in the NZ population aged 8 and 12 years, 22.0% were reported to have Maori ethnicity, 7.7% Pacific Island ethnicities and 67.3% NZ European and other ethnicities in the 2001 NZ Census (Statistics NZ, personal communication).

Ambient environmental conditions

A summary of the daily ambient, on-site UVR, temperature and humidity is provided in Table 1. Seasonal and latitudinal differences in total daily ambient UVR were evident, with high values recorded in the Auckland and Hamilton (Waikato) regions during summer in December and February, and low values recorded in Canterbury during early autumn in April.

Total daily UVR exposure

For all person-days, the arithmetic mean total daily UVR exposure between 7:00 and 20:00 h was 0.92 SED (median = 0.63 SED; inter-quartile range = 1.16 SED). Figure 3 shows the log-normal distribution of total daily UVR exposures for all children for all days. Much of the range of exposures in Fig. 3 results from geographic differences in the schools sampled and the seasons during which the schools were visited. Had this study been conducted year-round, we would expect a distribution with a greater number of lower exposures. Almost half (43.6%) of the sample received between 0 and 0.5 SED per day and 22.2% received between 0.5 and 1 SED per day. As UVR exposures followed a skewed distribution, these data were log-transformed for all further analyses.

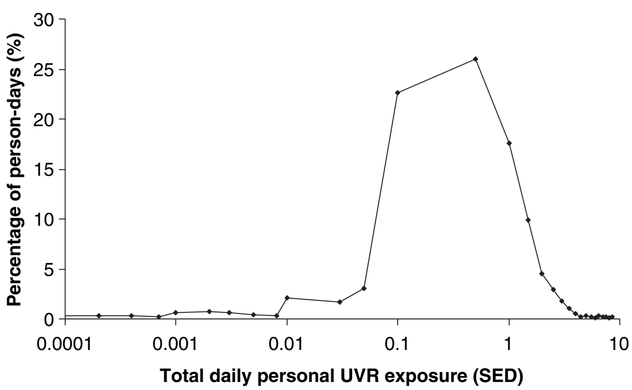

Figure 3. Total daily UVR exposure (SED) showing the log-normal nature of the distribution.

Time spent outdoors

Children spent, on average, 2.3 h outdoors per day between 7:00 and 18:00 h. Of their total time spent outdoors each day, 57.2% was between 11:00 and 16:00 h. There were no statistically significant differences in time spent outdoors by sex or year level. However, children spent a longer mean time outdoors during weekend days (2.6 h) than weekdays (2.2 h) (P = 0.042), although for weekend days less time was spent outdoors during high UVR hours (11:00–16:00 h) compared with weekdays, resulting in greater weekday UVR exposures than weekend UVR exposures (see below).

Outdoor UVR exposure as a percentage of ambient UVR and activity

The mean outdoor UVR exposure and mean outdoor UVR exposure as a percentage of ambient UVR, for identical durations, is presented by year level, sex and day of the week in Table 3. The overall mean outdoor UVR exposure as a percentage of ambient UVR was 4.9%. Table 4 presents mean outdoor UVR exposure rates (mSED min^{-1}) for the five high-level outdoor activity categories and Fig. 4 shows the UVR exposure levels, by these categories, for weekdays and weekend days.

Differences in UVR exposure as a percentage of the ambient UVR exposure were largely explained by day of the week (with higher percentages on weekdays) (P < 0.0001), and an activity–year level interaction (the activities of younger children, although labeled the same, resulted in different UVR exposure patterns than among older children) (P < 0.0001). This interaction applied for outdoor passive, travel and active pursuits, but not for in shade or in vehicle pursuits. There was no statistically significant sex effect.

Table 3. Mean total outdoor UVR exposure between 7:00 and 18:00 h (NZST + 1), mean outdoor UVR exposure as a percentage of the ambient UVR levels for the appropriate times, and time spent outdoors (hours day^{-1}) by year level, sex and day of the week.

	Mean total outdoor UVR exposure (SED)	Mean outdoor UVR exposure as % ambient UVR	Mean outdoor UVR exposure as % ambient UVR (between 11:00 and 16:00 h)	Mean time spent outdoors (h)
All participants	0.32	4.9	2.5	2.3
Year level				
Y4	0.26	4.3	2.3	2.1
Y8	0.37	5.4	2.7	2.4
Sex				
Male	0.35	5.0	2.6	2.3
Female	0.40	4.9	2.4	2.3
Day of the week				
Weekdays	0.39	5.8	3.7	2.2
Weekend	0.14	2.4	1.6	2.6

Note: 1 SED = 100 J m^{-2}. Reported mean values are geometric mean values.

Table 4. Mean outdoor UVR exposure rates (mSED min^{-1}) for high-level outdoor activity categories.

	Outdoor passive	Outdoor active	Outdoors in shade	Outdoor travel	Outdoor unclassified
Mean outdoor UVR exposure rate	3.11	2.15	1.71	1.37	1.39
Mean overall duration (min)	38.9	45.5	39.8	27.6	48.9
Time spent between 11:00 and 16:00 h (%)	76.2	52.0	59.6	52.1	56.5

Note: 1 mSED min^{-1} = 0.001 SED min^{-1}. Reported mean values are geometric mean values.

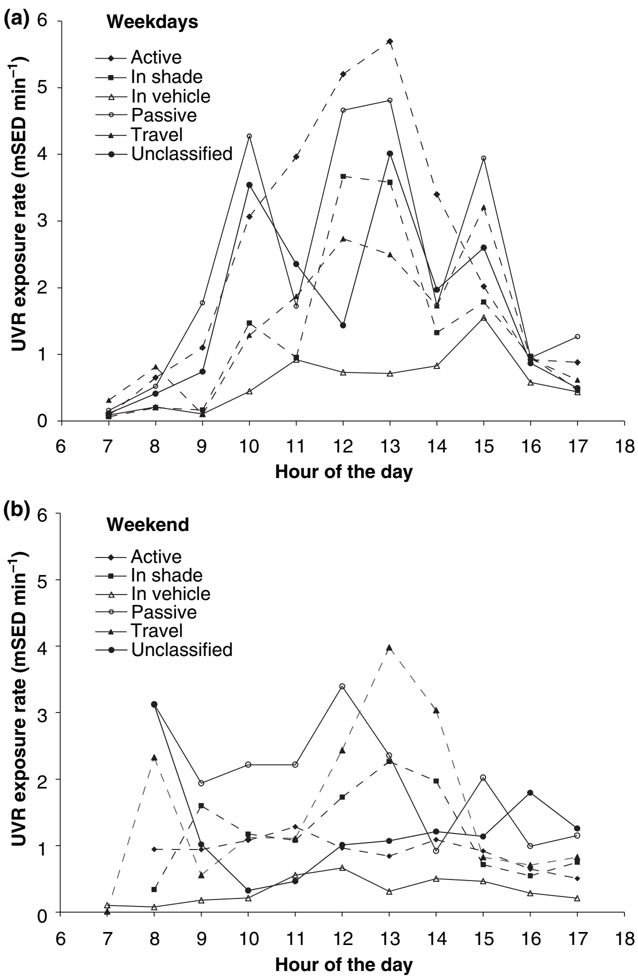

Figure 4. UVR exposure rates (mSED min^{-1}) for each activity category, for (a) weekdays and (b) weekend days.

Sun protection coverage scores

Table 5 presents the mean sun protection coverage scores for each high-level activity category by school year level, sex and day of the week. There were no statistically significant differences for sun protection coverage scores by sex or day of the week; however, there was a statistically significant activity–school year level interaction ($P = 0.01$) where, for at least one pair of high-level activities, Y4 and Y8 scores were different, *e.g.* for outdoor active pursuits scores were 61.5% and 64.9% for Y4 and Y8 children, respectively. During the hours that the Cancer Society of NZ recommends particular attention to sun protection (11:00–16:00 h) hats were worn on average 26.3% of the time when children were outdoors, and most used during passive pursuits (38.8%). Sunglasses and sunscreen were the least used of all sun-protective practices, worn 3.6% and 8.6% of the time children spent outdoors, respectively.

Specific high UVR exposure activities

Specific activities which were associated with the highest UVR exposure rates are shown in Table 6, ranked in order of mean UVR exposure rate. To facilitate generalization, activities were only included if they occurred for more than 10 person-days, overall. Mean sun protection coverage scores were also calculated with the highest score recorded for playing cricket.

Measured UVR exposure in relation to outdoor activity entries

A comparison of child UVR exposure by location, identified using activity diaries, provided a preliminary diary entry validation. Figure 5 presents the frequency and percentage of hourly UVR exposure rates for being inside, outside, in a vehicle and in shade using a frequency classification of 0, 0–0.01, 0.011–0.1, 0.11–1.0, 1.1–10.0 and greater than 10.0 mSED h^{-1}. The highest percentages of zero UVR exposures were recorded for being indoors (36.2%) and in a vehicle (30.8%). Conversely, the highest percentages for UVR exposure greater than 10.0 mSED h^{-1} were for outside (60.9%) and in the shade (59.9%). For outside and in shade pursuits, similar percentages were found for zero UVR exposure, being 19.8% and 18.2%, respectively.

DISCUSSION

As far as we are aware, this is the first study to present concurrent, quantified measurements of UVR exposure, activities and sun-protective practices among a large sample of primary schoolchildren (16) although numerous other studies have measured these factors either separately or in some incomplete combination (17–20). Three previous studies considered sun behavior and sun protection among NZ children, using parent report, but none reported time spent outdoors nor measured real-time UVR exposure and concurrent activities (49–51).

On average, NZ schoolchildren spent 2.3 h outdoors between 7:00 and 18:00 h, which compared well with South African (2.3 h) (17) and Australian (2.2 h) (19) schoolchildren. Although NZ schoolchildren had relatively low total daily UVR exposure (mean 0.9 SED per day), they spent almost half of their time outdoors between 11:00 and 16:00 h and received three-quarters of their total daily UVR exposure during this

Table 5. Mean sun protection coverage scores (%) for each outdoor activity category by year level, sex and day of the week.

	Outdoor passive	Outdoor active	Outdoors in shade	Outdoor travel	Outdoor unclassified	In a vehicle	All activities
All participants	73.4	63.6	72.0	71.8	72.2	73.4	70.2
Year level							
Y4	74.6	61.5	71.9	71.4	72.1	74.2	69.8
Y8	72.7	64.9	72.1	71.9	72.3	73.0	70.4
Sex							
Male	72.2	60.4	70.0	70.0	70.2	72.6	68.0
Female	74.3	66.6	74.2	73.2	73.9	74.0	72.0
Day of the week							
Weekday	73.3	63.1	71.8	71.3	71.6	72.8	69.9
Weekend	75.7	66.3	73.6	74.5	74.0	75.8	72.4

Table 6. Specific activities ranked by mean UVR exposure rates (mSED min^{-1}).

Specific outdoor activity	Person-days (*N*)	Mean UVR exposure rate (mSED min^{-1})	Mean duration (min)	Mean UVR exposure rate between 11:00 and 16:00 h (mSED min^{-1})	Mean duration between 11:00 and 16:00 h (min)	Mean sun protection score (%)
Physical education (A)	89	5.9	42.1	5.5	42.6	71.1
Athletics (A)	13	4.4	170.1	9.3	143.9	74.3
Lunch (P)	600	4.4	53.8	4.4	53.8	73.2
Walked home (T)	78	4.3	26.9	4.6	26.4	70.6
Cricket (A)	11	4.1	122.5	8.3	79.1	79.2
Working (P)	12	4.0	37.4	4.6	39.5	77.3
Morning tea (P)	365	3.3	23.2	1.9	17.6	73.2
Play time (A)	30	3.2	31.9	3.2	23.0	75.1
Tennis (A)	53	3.2	60.0	7.6	51.1	69.0
Biked home (T)	12	2.8	23.6	3.0	23.0	65.1

Note: 1 mSED min^{-1} = 0.001 SED min^{-1}. A = outdoor active; P = outdoor passive; T = outdoor travel. Reported mean values are geometric mean values.

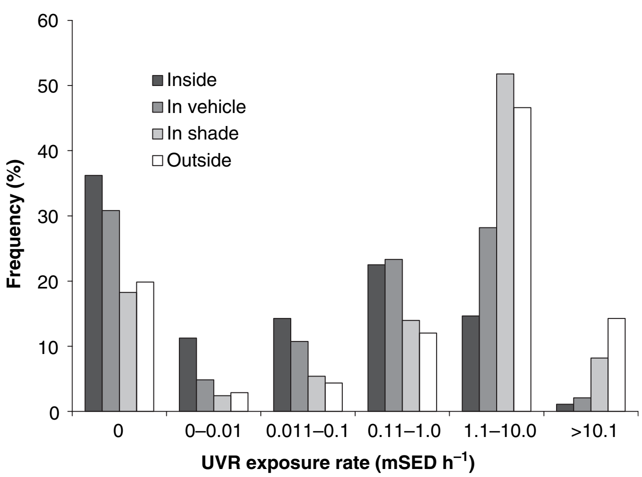

Figure 5. Frequency of UVR exposures, classified according to six bands, by location as reported by the children in their activity diaries.

time period. Some children still received sufficient UVR (*i.e.* greater than 5 SED per day, see Fig. 3) depending on skin type, to elicit sunburn on some study days. Children are encouraged by the Cancer Society of NZ to minimize sun exposure between 11:00 and 16:00 h. Schools have an important part to play considering, for example, lunch breaks (approximately 12:30 h) fall within this period.

Comparing our results with those of other UVR dosimetry studies among children is difficult because of the differences in study design such as anatomical attachment site of UVR monitor, type of instrument used, latitude and season. Calculation of the total daily UVR exposure as a percentage of the ambient UVR was chosen to reduce the effect of seasonal, latitudinal and time of day differences in the analysis. However, we acknowledge that possible geographic differences may exist because they acted as a surrogate measure for differences in ambient UVR, in relation to the season in which a school was visited (mid-summer compared with late spring). In addition, actual levels of UVR exposure that were affected by albedo may, in specific cases, have differentially influenced the calculated percentage of the ambient UVR level, but this is unlikely to have significantly influenced the overall direction of the levels reported for the aggregated data. Total daily UVR exposure as a percentage of ambient UVR was 2.8%, compared to children in South Africa (summer, 4.6%) (17) and Denmark (annual, 5.1%) (20). When outdoor UVR exposure was calculated (using the activity diaries) as a percentage of the ambient UVR for the same exposure periods, this percentage increased to 4.9%, possibly a more reliable estimate, depending on activity diary entry accuracy. However, anatomic differences in UVR exposure measurement persist and, although exposure ratios for different anatomic sites have been calculated using mannequins and humans (52,53), there are no standardized exposure ratios for children.

This study was unique in that it combined quantified, time-stamped UVR exposure measurements with concurrent activities and sun-protective practices. At the highest classification level, outdoor passive pursuits were associated with slightly higher UVR exposure rates compared to outdoor active pursuits (see Table 4). This is not unusual, as passive activities entail less movement and the UVR monitor may be held reasonably still, possibly angled directly toward the sun, for longer periods when in a resting position compared to during movement. Outdoor pursuits in shade were associated with lower UVR exposure rates than outdoor passive and active pursuits. Similarly, Danish schoolchildren (5–6 years) playing in a shady playground received 33% lower UVR exposures than schoolchildren (1–4 years) in a sunny playground (54). There is, therefore, some evidence for encouraging the use of shade as a sun protection option amongst schoolchildren.

When considering all factors influencing outdoor UVR exposure as a percentage of the ambient UVR exposures, we found that for all children, outdoor UVR exposure as a percentage of the ambient UVR was higher on weekdays than on weekend days. This may have been a consequence of better monitor wearing behavior at school on weekdays, when researchers provided daily reminders which were not possible on weekend days. However, activity diary entries indicated that more time was spent outdoors on weekend days when children may have greater choice in choosing outdoor *versus* indoor activities compared to weekdays, although less of this time was during high UVR hours (11:00–16:00 h).

A school year level–activity interaction was identified where, for at least one pair of high-level activities, Y4 children experienced different outdoor UVR exposures as a percentage of the ambient UVR compared to Y8 children. Although this indicates that activity is an important factor influencing UVR exposure, several other explanations are plausible. Y4 children may have been less diligent than Y8 children in recording individual outdoor activities, thereby diluting the recorded activity by not including all activities undertaken. In addition, the behavior associated with an activity code may have differed between year levels, where the word used by Y4 children to describe the activity may have meant something different when used by Y8 children. For example, soccer for a Y8 child may have meant playing a soccer game, whereas for a Y4 child it may have meant kicking a soccer ball around on their own. Furthermore, Y4 children may have been supervised differently to Y8 children, with resultant difference in behavior. The high-level classification system used to categorize activities may have also masked real difficulties or revealed artificial differences. Finally, differences between Y4 and Y8 children with respect to bodily movement and orientation of the UVR monitor toward the sun may also contribute to explaining some of this effect.

In a previous NZ study, parental report and observation indicated that sun protection was generally high for children (0–10 years) at the beach and playgrounds (50). Moreover, there was a highly significant association between child hat-wearing and sunscreen use and 73% of the sample wore either a hat or sunscreen when outdoors on the Sunday investigated. We found that, overall, self-reported sun protection by activity indicated moderate coverage (70%), representing such combinations as shorts, t-shirt and hat, or shorts and a long-sleeve shirt, but no sunscreen.

When interpreting the results of this study, some caveats should be noted. For logistical reasons, schools were the principal sampling frame for the study. Therefore, the sample was not a randomly selected representative sample of the NZ population. However, this would not affect the relationship between measured UVR exposure and activities undertaken. Care should be taken in generalizing UVR exposure rates to different populations, especially those in different climates, as patterns of exposure may be quite different. Some children declined to participate due to the perceived cumbersomeness of study tasks, thus reducing the participation rate.

Many UVR exposure studies have used retrospective questionnaires to examine sun-related behavior and are therefore subject to recall bias (55–59). In this study, compliance was encouraged by having a researcher on site each morning during weekdays to remind children to complete their activity diary frequently throughout the day and ensuring teachers, parents, caregivers and fellow schoolchildren were supportive of full participation. Recently, compliance and data reliability in UVR exposure studies using electronic UVR dosimeters and retrospective diaries were investigated and an average estimated error rate of 6.3% was calculated for children (60). The diary used in that study required ''Yes'' or ''No'' answers to eight questions such as ''have you exposed your shoulders or upper body outdoors today'' and ''have you been at the beach or at the sea today.'' The activity diary used in our study sought greater detail and children were encouraged to fill out their activities frequently during the day to minimize recall problems. We carried out a simple validation of UVR exposure measurements according to self-reported indoor–outdoor status. We hypothesized that most indoor UVR exposure rates would be 0, but some would be greater than 0 when a child was sitting beside an open window. We hypothesized most vehicular UVR exposure rates would be low as UV-B transmission through most types of automobile glass is relatively low ($<10\%$) (61) and in one study, UVR exposure of the arms was estimated to be 3–4% of the ambient UVR when car windows were shut (62). We hypothesized that the majority of outdoor and in the shade UVR exposure measurements would be higher than in a vehicle and indoor measurements. That the UVR exposure rates did not always match the indoor–outdoor status recorded by the child was probably due to some UVR received through glass (where glass type varies) while indoors or in a vehicle, or sitting besides an open window. Vehicular travel is often not continuous and getting out of the vehicle during brief stops may have resulted in some outdoor UVR exposure not recorded by the child in their diary. Activities were recorded to 10-min periods whereas UVR exposure was recorded at 8-s intervals. Frequent changes in UVR exposure rates within the 10-min period would have been recorded by the UVR monitor, but no allowance was made for recording in the activity diary activities of less than 10 min duration. Moreover, children may have made timing errors when recording activities. We found reasonable reliability between the two data streams, possibly due to researcher efforts for high compliance and, therefore, increased reliability. For outside and in the shade activities similar percentages were found for zero UVR exposures, with 19.8% and 18.2%, respectively, thereby highlighting the need for a study that required more detailed diary entries to describe the quality of exposure (*e.g.* type of shade, proximity to shade) and, perhaps, at 5-min rather than 10-min intervals, which might help validation of UVR exposure and diary entries. However, this would increase the burden of tasks on the children. Future UVR exposure studies carried out among children may also consider alternative activity recording options, such as using a mobile phone or handheld personal digital assistant which, although currently costly, may encourage children (depending on age) to participate and, potentially, may improve compliance, accuracy of activity recording and alleviate the burden of manually entering activity diary data postfieldwork.

Acknowledgements—This project was initiated and undertaken by the Social & Behavioural Research in Cancer Group with funding from the Cancer Society of NZ Inc. The views expressed are not necessarily those of the Cancer Society of NZ Inc. During the preparation of this paper, Dr. Reeder and the Social & Behavioural Research in Cancer Group received funding from the Cancer Society of NZ Inc. and the University of Otago. Associate Professor Cox received funding from the Director's Cancer Research Trust. Ms Wright received support from the National Research Foundation of South Africa, the National Institute of Water and Atmospheric Research and the University of Otago. V. Hammond, Dr. R. McKenzie, N. Huston, J. Jopson, H. Shiona, M. Allen and M. Kotkamp are acknowledged for their contributions to the project. Special thanks for their cooperation are due to all of the NZ principals, teachers, children, caregivers and health promoters who made the study possible.

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