

Measurements of occupational ultraviolet exposure and the implications of timetabled yard duty for school teachers in Queensland, Australia: preliminary results

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Keywords: Ultraviolet, occupation, skin cancer, dosimetry.

Abstract

Simultaneous personal measurements of the occupational ultraviolet exposure weighted to the International Commission on Non-Ionizing Radiation Protection hazard sensitivity spectrum (UV_{ICNIRP}) were made over a five week period (44 person-days) in the second half of the summer school term of 2012 in Queensland, Australia for individual high school teachers located at latitudes of 27.5°S and 23.5°S. These teachers were employed for the duration of the study in a predominately indoor classroom teaching role, excluding mandatory periods of lunch time yard duty and school sport supervisions. Data is presented from personal measurements made to the shirt collar using polyphenylene oxide (PPO) film UV dosimeters. UV_{ICNIRP} exposure data is presented for each week of the study period for the shirt collar measurement site and are further expressed relative to the measured ambient horizontal plane exposure. Personal exposures were correlated with time outdoors, showing a higher exposure trend on days when teachers were required to supervise outdoor areas for more than 2 hours per week (mean daily exposure: $168 \text{ J m}^{-2} UV_{ICNIRP} \pm 5 \text{ J m}^{-2} (1\sigma)$) compared to the study average (mean daily exposure: $115 \text{ J m}^{-2} UV_{ICNIRP} \pm 91 \text{ J m}^{-2} (1\sigma)$). Time spent in an open playground environment was found to be the most critical factor influencing the occupational UV_{ICNIRP} exposure. A linear model was developed showing a correlation ($R^2= 0.77$) between the time teachers spent on yard duty and UV_{ICNIRP} exposure, expressed relative to ambient. The research findings indicate a greater reduction in personal exposure can be achieved by timetabling for yard duty periods in playground areas which offer more shade from trees and surrounding buildings. All mean daily personal exposures measured at the shirt collar site were higher than the ICNIRP occupational daily exposure limit of 30 J m^{-2} for outdoor workers.

1. Introduction

Skin cancers and eye disorders such as cataracts caused by exposure to solar ultraviolet radiation (1) are a significant cost burden to health authorities throughout the world. In Australia, the cost burden for diagnosing and treating non-melanoma skin cancer alone has been measured at over \$264 million (2) and compares to an annual skin cancer treatment cost in the United States of over \$2 billion (3). The cost in Australia is exceedingly high because of two primary factors. Firstly, a very high ambient ultraviolet climate due to high annual solar elevation in the mid to low latitudes of Australia's geographic location, lower moderation of biologically significant ultraviolet B (UVB: 280 to 320 nm) due to generally lower stratospheric ozone concentrations compared to the northern hemisphere and a closer earth sun distance during the southern hemisphere summer compounding the threat posed by the naturally available UVB spectrum. Secondly, an outdoor lifestyle promoted by a warm Australian climate and a predominately fair skinned population increases the risk of over exposure and the development of skin cancer. Excessive exposure to this UVB radiation is preventable and strategies promoted by public health campaigns such as the Australian "Slip Slop Slap" and "SunSmart" public education program advocate improving sun-related attitudes and behaviour with the result being an increased awareness among the population compared to earlier decades for an estimated 22 000 life years saved since the program's introduction in the 1980's (4). Also on the positive side, there has been a recent stabilization in mortality rates for melanoma skin cancer across Australia, the US and European countries (5). However, the worldwide disease burden in terms of cost and incidence continues to rise (5). In Australia, over 1200 deaths are attributed to the development of melanoma skin cancer with more than 400 deaths being attributed to the development of other types of non-melanoma skin cancer annually (6).

Deaths due to non-ionising exposure to ultraviolet radiation as a result of occupation are more difficult to analyse statistically. This is largely due to limited information being available on lifetime exposure habits. Interestingly, occupations which require long periods of time outdoors, construction and outdoor labouring positions for example, do not show a strong correlation with skin cancer (7, 8).

Lee and Strickland (9) report a lower incidence and mortality from malignant melanoma for unskilled workers compared to professional and administrative workers whose occupation places them largely in an indoor environment. Yet exposure to UVB radiation is known to be the most significant risk factor for the development of malignant melanoma, the most common type of cancer in fair skinned populations (5). This has been deduced from studies of past lifetime sun exposure histories, a large bank of information linking high skin cancer incidence to high UVB ambient climates such as those experienced in Australia and studies involving animals (10).

Intermittent exposure to sunlight received as a consequence of occupation has been found to induce melanoma (11). Intermittent exposures for workers placed into primarily indoor roles remains an important risk factor to be studied in order to better determine the epidemiology of sun related disease. Of those indoor population groups at risk of exposure to non-ionising UVB, school teachers are particularly interesting as they are largely employed in indoor classroom roles but must also frequently supervise children in an outdoor playground environment. Several studies have measured UVB exposure to school children and have been developed to explain the local ambient UV in a school playground (12, 13, 14). Other studies have examined the exposure received by school teachers themselves. Woolley et al. (15) recommended the mandatory use of appropriate sun protective clothing for individuals in high sun exposure occupations. Although limited to adult men, this study also noted that sun protection measures had a tendency to be adopted only by those who had a previous negative experience with skin cancer (15). Young teachers and school children are unlikely to have first-hand experience with skin cancer due to the tendency for a long latency period between exposure and the development of the disease.

Indeed, the importance of better understanding the UVB exposures received by indoor population groups has begun to gather momentum. A summary of personal exposures expressed relative to the available ambient ultraviolet for both indoor and outdoor occupational groups has been presented by Godar (16). A comparison of these studies show that exposures received by outdoor workers, including gardeners, lifeguards, physical education teachers and other outdoor occupations are

roughly twice that of indoor workers and vary depending upon the available ambient in which the studies were conducted (16). Studies conducted by Gies et al. (17) and Vishvakarmen et al. (18) have measured the biologically significant UVB exposure to school teachers and have provided a better understanding of the intermittent and cumulative lifetime exposures received by this indoor / outdoor occupational group, however these studies considered the exposure received by Physical Education teachers, who spend a proportionally high amount of time in an outdoor environment. In this research, a long term UVB dosimeter was employed to quantify the exposure received by school teachers employed primarily as indoor classroom teachers with specific reference to the International Non-Ionizing Radiation Committee recommendations on occupational exposure limits to biologically significant UVB.

2. Materials and Methods

A personal UV monitoring program was established over a consecutive five week period of the Queensland school teaching term running from 29 October to 30 November, 2012. The study period coincides with seasonal peak ultraviolet playground exposures in the Australian school teaching calendar, ending in mid December, toward the approach of summer solstice for summer break and beginning again in late January, a time when the earth sun distance is at a minimum. Both school populations, including children and staff in this study were of a predominantly fair skin type (Fitzpatrick skin type Type I and Type II).

The monitoring program measured the incident ultraviolet radiation weighted to the occupational ultraviolet hazard sensitivity standard (UV_{ICNIRP}). The UV_{ICNIRP} represents the spectrally weighted occupational exposure standard and is based on the amended 1989 guidelines on exposure limits to UV radiation received by the skin or eye of the International Non-Ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA) (19). The IRPA (20) standard

has been issued as the threshold limiting exposure of the World Health organisation (21) and may be taken as representative of the upper daily exposure limit for the working population. The UV_{ICNIRP} exposure applies a lower spectral weighting to wavelengths below a normalised peak at 290 nm than other comparative action spectra and when weighted, is lower than exposures referenced to the erythemal action spectrum (22). Thus the measurements presented here are likely to be higher if taken as indicative of the human erythemal or sunburning response. The recommended exposure limit referenced to the occupational standard received by outdoor workers over an 8-hour daily exposure period is 30 J m^{-2} (19).

Measurements of personal UV_{ICNIRP} exposure were made for the current study to two Queensland high school teachers located in Toowoomba (27.5°S, 151.9°E) - participant A, and Emerald (23.5°S, 148.2°E) – participant B, Queensland, Australia. Both teachers were employed as indoor classroom teachers but were expected to partake in mandatory outdoor playground and sport supervision duties as part of their employment. Emerald, located at sea level is situated in a rural setting, while Toowoomba at 690 m altitude is a regional Australian city of approximately 125 000 people. Both cities have a limited industrial capacity and experience minimal air pollution, predominately clear skies and high ultraviolet exposure climates relative to other schools with similar fair skin type populations located in higher European or North American latitudes.

Measurements were made using a miniaturised version of a polyphenylene oxide (PPO) film dosimeter (23, 24, 25, 26, 27). These dosimeters are manufactured at the authors' research laboratory at the University of Southern Queensland, Toowoomba, Australia in thin film form to an approximate thickness of 40 microns. The film was attached to flexible polymer frames measuring 15 by 10 mm with a clear circular aperture of 7 mm. The PPO film dosimeters used have the advantage of an extended dynamic range compared to polysulphone and were used for five consecutive working days before replacement. Dosimeter sets exposed in Toowoomba and Emerald were calibrated to a predetermined calibration function:

$$UV_{ICNIRP} = -2595.2 \Delta A_{320}^2 + 8969 \Delta A_{320} \quad (1)$$

Here, UV_{ICNIRP} is the calibrated INIRC/IRPA (19) weighted UV, and ΔA_{320} is the change in dosimeter absorbance measured at 320 nm. The quadratic calibration function was determined by exposing a series of miniaturised PPO dosimeters between 5 and 9 November 2012 at the University of Southern Queensland, Toowoomba. Thus calibrated exposures measured to participant A are representative of same ambient conditions under which the calibration was performed for the early summer solar zenith angle range and ozone conditions. Measurements to participant B, while comparable to the calibration performed in the same month are prone to variations caused by potential differences in ozone and atmospheric particulates.

The dosimeters were calibrated to the UV_{ICNIRP} for the end of semester measurement period by comparing the relative change in PPO absorbance at 320 nm to the spectrally weighted UV (280 to 400 nm) measured by the University of Southern Queensland's DTM300 spectroradiometer, Bentham Instruments, Reading UK. This instrument has a calibrated uncertainty of $\pm 9\%$, traceable to the National Physical Laboratory, UK standard (28).

PPO dosimeters were attached to the rear shirt collar of both teachers using either a safety pin or clear adhesive tape before the commencement of each school day (8:30 am) and removed at the end of daily duties (3:15 pm). Here a sun exposure measurement campaign was implemented via the post with instructions on how to attach and handle PPO film dosimeters. Study participants were not monitored over the duration of the measurement campaign but instructed on where to attach dosimeters and how to store them in light proof envelopes at the end of each study day. The rear shirt collar site was chosen as this location was least likely to be tampered with by study participants (or touched by students) throughout the course of a working day. The chosen measurement site is indicative of exposures received by the back of the neck. Both study Participants were known to the authors and volunteered to participate in the collection of the exposure data. Ethics approval was granted to conduct the study (USQ ethics approval: H12REA174.1).

Dosimeters were replaced weekly and represent the exposure received over a maximum of five consecutive days in each working week. Exposed dosimeters were returned via the national postal service. Exposure data was collected over 44 person-days where each person-day represents a full working day during which a dosimeter was worn. Teachers were asked to submit their weekly timetable indicating periods of mandatory playground duty. Duty areas were noted as either open (school ovals), or partly shaded (under tree shade or located near buildings). Teachers also indicated periods when they may have been outdoors to account for non-routine outdoor exposure periods such as sport supervision field duties, fire drills, etc. Each dosimeter is therefore indicative of the occupational exposure received by both teachers for each working week.

To derive the ambient UV_{ICNIRP} , PPO dosimeters were simultaneously placed on a horizontal plane in an open region of each school playground during each of the weekly personal exposure periods (from 8:30 am to 3:15 pm daily). Measured personal exposures were compared to the recorded ambient for both playground environments over each of the 44 person-days in the study.

3. Results and Discussion

The weekly UV_{ICNIRP} exposure received by each teacher is listed in Table 1. The results are differentiated by location. For comparison, the ambient UV_{ICNIRP} measured for each week that the participants were working is also provided. The personal exposures measured for each week of the study to the rear of the shirt collar exceed the recommended occupational exposure limit of 30 Jm^{-2} per day where this limit can be expressed as a weekly value when multiplied by the respective working days for each teacher, ranging in this study from a minimum weekly limit of 90 Jm^{-2} for the shortest working period of three days to 150 Jm^{-2} (5 x 8-hour days). Figure 1 shows the average daily UV_{ICNIRP} exposure of both teachers for the five week study duration.

TABLE 1

FIGURE 1

Total exposure time for both study participants was less than two hours per week excluding weeks 3 and 5 for participant B during which total weekly yard duty exposure times were 125 minutes weekly for both weeks. This increased the average daily exposure received by participant B in weeks 3 and 5 to $168 \text{ J m}^{-2} \text{ UV}_{\text{ICNIRP}} \pm 5 \text{ J m}^{-2} (1\sigma)$ compared to the study mean daily exposure of $115 \text{ J m}^{-2} \text{ UV}_{\text{ICNIRP}} \pm 91 \text{ J m}^{-2} (1\sigma)$ which was received over a study average yard duty exposure time of 92.5 minutes per week.

The dosimeter measurement site received a low exposure relative to the available ambient $\text{UV}_{\text{ICNIRP}}$ for both participants ($11\% \pm 7\% (1\sigma)$). This is a consequence of two factors, firstly, the shirt collar site receives a low proportion of the available radiation when expressed relative to the incident horizontal plane exposure being oriented nearer to a vertical plane of incidence, and secondly teacher location during working hours limits the outdoor exposure time to the available ambient UV. Notwithstanding that the face receives a higher proportion of the available ambient than the back of the neck for individuals orientated in an upright position during periods of high solar elevation (29), the shirt collar measurements can be evaluated in this instance for each participant in terms of the resulting occupational outdoor behaviour pattern. The exposures expressed relative to ambient for both classroom teachers presented in this study is comparable with recent summaries of occupational exposure measured to outdoor workers using polysulphone film dosimeters (30).

3.1 Playground exposure times

Figure 2 compares the exposure for the study participants by time spent outdoors over the study period. The figure is a simplified UV heat map for indicating only the periods during each study week

that each teacher was required to be in the playground environment. A UV heat map shows each individual's weekly exposure regime during which dosimeters were attached to the rear shirt collar. A single line in the heat map represents the exposure pattern for each five day working week. Exposure patterns for each participant are shown for the five week duration of the study, starting with week one (the bottom line) and ending with week five (the top line) in each participant's weekly exposure set. Exposures in this case are taken as low (indoor periods), medium (outdoor periods in playground regions which offered shade) or high (outdoor periods in playground regions which offered no shade). The x-axis scale was divided into 5-minute periods and as such does not indicate times that may have occurred during brief intermittent exposures experienced for example when a teacher may have been walking between classes. The x-axis scale is further divided by day of the week starting at 8:30 am and ending at 3:15 pm on each day.

Participant A followed a fixed daily timetable and playground duty schedule as is indicated in the figure with the exception of an indoor professional development day on Tuesday in week 5. The staggered line duty system of participant B is evident in the figure when compared to the fixed playground duty routine of participant A. All mandatory playground exposures at both schools were scheduled between 11:00 am and 2:00 pm (morning tea and midday lunch breaks). These are indicated by medium or high exposure periods occurring near the middle of each day in the weekly exposure sets. Participant A was required for outdoor sport supervision duties on Wednesday afternoons between 2:00 pm and 3:00 pm. This is also evident in the figure occurring regularly near the end of each Wednesday exposure.

FIGURE 2

Both study participants were maths/science teachers and were required for indoor duty at all other times during the day between 8:30 am and 3:15 pm. Indoor UV_{ICNIRP} exposure is likely to be minimal at these times, excluding brief periods of classroom transition. Therefore it is reasonable to postulate that the measured weekly UV_{ICNIRP} exposures presented in Table 1 are the cumulative sum of the

outdoor exposures received during playground duty and sport supervisions illustrated by the high and medium exposure periods in figure 2. Exposures to participant B were the highest recorded. This was not likely to be due to the influence of latitude alone as indicated by the generally lower ambient UV_{ICNIRP} exposures in Emerald compared to Toowoomba during the study period (Table 1). Furthermore, participant B spent less time in an outdoor environment (including medium and high exposure periods) over the 5 week study compared to participant A, spending a total of 425 minutes on duty compared to 570 minutes for participant A.

The difference in exposure for both participants is due to outdoor exposure behaviour and is a direct consequence of defined playground duty area. Participant A was required to supervise near and under buildings for all scheduled playground duty and sport supervision periods per week excluding one period in an open environment received on Tuesdays. Participant B spent a greater amount of time in regions which offered limited or no shade at all. The exposures received by participant B also occurred at irregular intervals in the week due to a staggered line duty system. Thus, both participants spent different periods of time in predominantly shaded and open playground regions, with participant A experiencing a total open playground region exposure of 150 minutes over the 5 week study compared to 230 minutes in an open playground region for participant B.

It is clear that total UV_{ICNIRP} exposure is influenced by the type of playground duty environment. Regions that offer some sky cover, either due to tree shade, nearby buildings or protected walkways reduce the potentially negative influence of total outdoor playground duty time. The percentage of predominately open playground exposure time to total outdoor exposure time varied from 20% to 65% for participants A and B respectively. Significantly, participant B received a higher proportion of the total available ambient exposure for each week in the study period (Table 1), a likely consequence of spending more time in high exposure playground environments. Note however, the possible erroneous data point marked for participant B. This point may be the consequence of a film inconsistency or a fingerprint having a calibrated exposure of 1287 Jm^{-2} and occurring when participant B spent a total weekly time of 25 minutes in an open outdoor environment (week 2).

3.2 Measuring the influence of playground region

The influence of playground shading is evident in Figures 3(a) and (b). The figure compares the calibrated UV_{ICNIRP} exposure of both participants to the total outdoor playground exposure time for each week in the study period and excludes participant B's week 2 exposure, being a possible outlier in the collected data set. In figure 3(a), personal UV_{ICNIRP} exposure is plotted against total playground time. Figure 3(b) plots the personal UV_{ICNIRP} exposure against exposure time in open playground environments only. The influence of the playground environment is immediately evident in the improved correlation of figure 3(b).

FIGURE 3a	FIGURE 3b
FIGURE 3c	FIGURE 3d

The correlation of figure 3(b) was improved when a weighting factor was added to the shaded region playground exposure times. Figure 3(c) plots the personal UV_{ICNIRP} exposure measured for each week of the study period to both participants with an effective shaded playground exposure weighting of 10%. Thus, for figure 3(c), the weighted playground exposure in minutes was determined using:

$$T_w = T_o + 0.1T_s \quad (2)$$

where T_w is the total weighted exposure time plotted in figure 3(c), T_o is the total open playground exposure time and T_s is the total shaded playground exposure time. The modification factor is

consistent with the findings of Downs and Parisi (31) where personal playground exposures weighted to the erythemally effective UV were found to vary from less than 1 SED to greater than 3 SED between students spending their day indoors compared to those who spent more than one school teaching or break period in an outdoor school playground environment.

Figure 3(c) implies that teachers on duty in shaded playground regions receive a reduction in their personal UV_{ICNIRP} exposure. The correlation between personal exposure expressed as a ratio of the ambient weekly exposure to the weighted outdoor playground exposure time strengthens the validity of this point (Figure 3(d)). Here the correlation improves due to the removal of ambient UV_{ICNIRP} variations, such as might occur due to cloudy or overcast periods, when the exposure data is expressed relative to the recorded ambient.

The improved correlation of Figure 3(d) demonstrates that weekly playground duty schedules, expressed in minutes per week can be used as a rough guide to predicting the proportion of ambient UV_{ICNIRP} that teachers can expect to receive per working week. That is:

$$UVB_{ratio} = 0.002(T_o + 0.1T_s) \quad (3)$$

Where UVB_{ratio} is the relative proportion of the ambient UV_{ICNIRP} received by a teacher due to playground duty, T_o is the total weekly exposure time spent in open playground environments and T_s is the total weekly exposure time spent in shaded playground environments where both weekly exposure times are expressed in minutes.

It must be acknowledged however that the small dataset presented here needs to be expanded over a much larger teacher sample and for schools located in different environments to improve the statistical validity of such a model. The model does however clearly indicate that the proportion of the available weekly ambient exposure is dependent upon the total time spent on yard duty and that time spent in predominately open playground environments increases this proportion. Using the weekly

average ambient UV_{ICNIRP} of both Emerald and Toowoomba of approximately 4500 Jm^{-2} , a teacher could expect to exceed a weekly occupational exposure limit of 150 Jm^{-2} in 17 minutes of exposure in open playground environments or 170 minutes if playground duty is restricted to predominately shaded regions.

4. Conclusions

- UV_{ICNIRP} exposures measured to the rear shirt collar site of two teachers located at different southern hemisphere latitudes were found to exceed the ICNIRP occupational limit of 30 Jm^{-2} for an 8 hour working day. These exposures were measured to teachers whose predominant working role is confined to an indoor classroom environment and whose average weekly yard duty is 92.5 minutes.
- Latitude or the total available ambient UV_{ICNIRP} in a school environment were not as significant to occupational exposure threshold as the total amount of time spent outdoors by teachers on playground duty.
- School yard duties requiring teachers to use open playground environments have a greater influence on weekly cumulative UV_{ICNIRP} exposure than total time spent outdoors. Strategies or yard duty schedules which mandate frequent use of shade for teachers rostered on areas that provide little shade including for example school ovals or open playground regions, can greatly increase the period of time a teacher can supervise outdoor regions of a playground before reaching the occupational safety threshold.
- Exposure to ultraviolet radiation has the potential for both beneficial and harmful influences on human health. Exposures received by the skin or eye in excess of 30 Jm^{-2} daily should be considered harmful and measures should be implemented for individuals placed into working environments which exceed these guidelines.

- A linear model based on an initial dataset has been presented here as an evaluation of the ambient UV_{ICNIRP} ratio received by a teacher on yard duty. A more statistically rigorous model, developed from a much larger population of teachers may provide a quantitative method to inform teachers and administrators of occupational exposure risk and assist with the planning of future safer yard duty schedules.
- Extended exposure range PPO dosimeters were trialled for use in this study to establish if the lower need to replace dosimeters daily would improve the likely affirmative repose of potential study participants to engage in future sun exposure trials. The loss of daily exposure information that may have been available if collected using lower range polysulphone dosimeters over the 5 week trial period reduced the resolution in information that has been presented here instead as daily averages, but has potential for future mass recruitment campaigns which ease the personal burden of participants needing to replace dosimeters daily.

Acknowledgements

The authors acknowledge the cooperation of the two school principals of the study participants for their assistance. The authors would also like to thank the Faculty of Health, Engineering and Sciences at the University of Southern Queensland for funding the UV laboratory equipment utilised in this research.

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Tables

Table 1: UV_{ICNIRP} weekly exposure measured to the rear shirt collar of participant A and participant B in comparison to the received ambient UV_{ICNIRP} exposure measured simultaneously on a horizontal plane in the school playground (# Dosimeter damaged, *possible outlier).

Week	Toowoomba – participant A				Emerald – participant B			
	Days worked	Shirt Collar UV_{ICNIRP} (Jm^{-2})	Ambient UV_{ICNIRP} (Jm^{-2})	Shirt collar/ Ambient	Days worked	Shirt Collar UV_{ICNIRP} (Jm^{-2})	Ambient UV_{ICNIRP} (Jm^{-2})	Shirt collar/ Ambient
29.10.2012 – 02.11.12	Full week	#	5053	#	Wed Thurs Fri	180	2726	0.07
05.11.12 – 09.11.2012	Full week	453	5513	0.08	Mon Tues Wed Thurs	*1287	5251	0.25
12.11-.2012 – 16.11.2012	Tue Wed Thus Fri	153	3292	0.05	Full week	821	4025	0.20
19.11.2012 – 23.11.2012	Tue Wed Thurs Fri	256	4676	0.05	Full week	420	3875	0.11
26.11.2012 – 30.11.2012	Full week	224	6584	0.03	Tue Wed Thurs Fri	686	4883	0.14

Figures

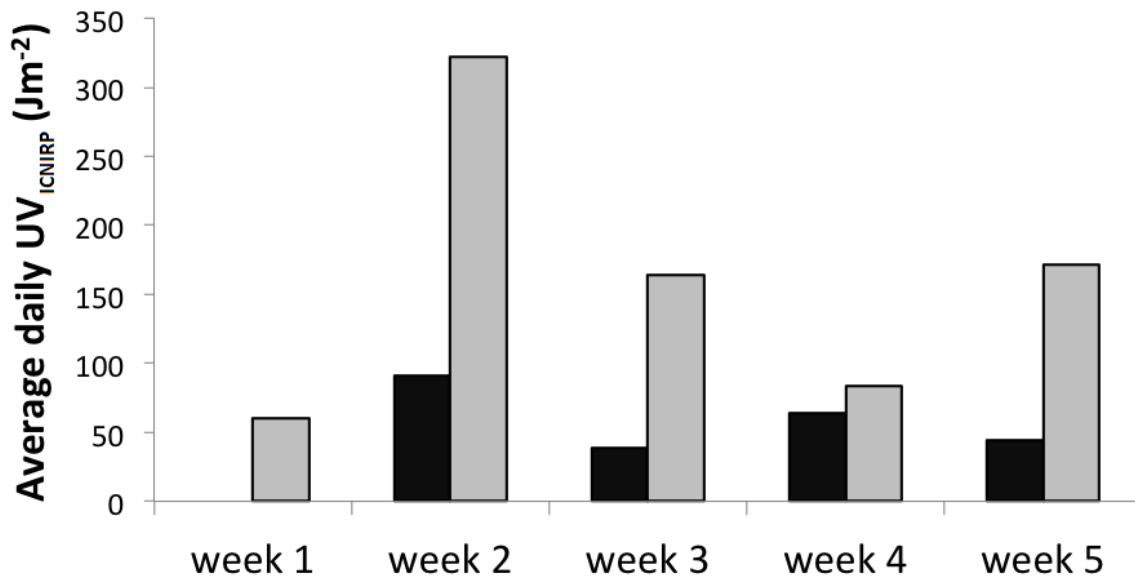


Figure 1: Average daily exposure for each week of the study period indicated for participant A - solid fill and participant B- light fill. (The weekly exposure received by participant B, week 2, is excessively high and may have been caused by a dosimeter measurement error.)

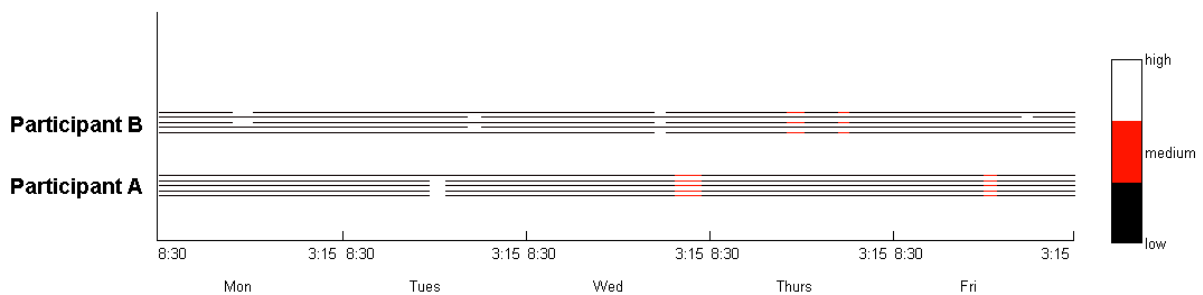


Figure 2: Periods of outdoor exposure represented as a UV heat map for each day in the 5 week study period ascending from the bottom (week 1) to the top (week 5) for both participant A and participant B showing periods of high exposure (outdoor periods in playground regions which offered no shade), of medium exposure (outdoor periods in playground regions which offered shade) and of low exposure (indoor periods).

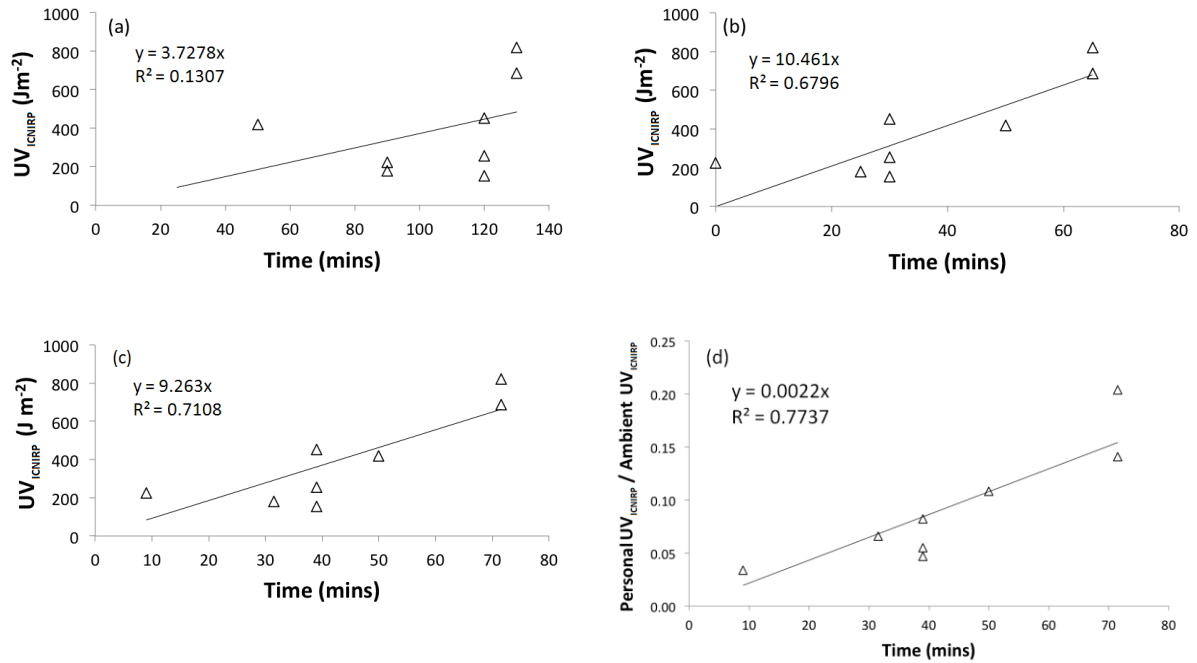


Figure 3: Comparison of personal weekly UV_{ICNIRP} exposure plotted against playground exposure time. (a) Exposure time is the total playground exposure time, (b) Exposure time is the time spent in open playground environments only, (c) Personal weekly UV_{ICNIRP} exposure against weighted playground exposure time where shaded playground regions are assigned a weighting of 10%, (d) Personal UV_{ICNIRP} exposure expressed relative to the ambient UV_{ICNIRP} exposure measured upon a horizontal plane in each school playground versus the weighted exposure time spent in an outdoor environment (Eqn 2).