Solar ultraviolet and the occupational radiant exposure of Queensland school teachers: a comparative study between teaching classifications and behavior patterns

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Abstract

Classroom teachers located in Queensland, Australia are exposed to high levels of ambient solar ultraviolet as part of the occupational requirement to provide supervision of children during lunch and break times. We investigated the relationship between periods of outdoor occupational radiant exposure and available ambient solar radiation across different teaching classifications and schools relative to the daily occupational solar ultraviolet radiation (H_{ICNIRP}) protection standard of 30 J/m^2. Self-reported daily sun exposure habits (n=480) and personal radiant exposures were monitored using calibrated polysulphone dosimeters (n=474) in 57 teaching staff from 6 different schools located in tropical north and southern Queensland. Daily radiant exposure patterns among teaching groups were compared to the ambient UV-Index. Personal sun exposures were stratified among teaching classifications, school location, school ownership (government vs non-government), and type (primary vs secondary). Median daily radiant exposures were 15 J/m^2 and 5 J/m^2 H_{ICNIRP} for schools located in northern and southern Queensland respectively. Of the 474 analyzed dosimeter-days, 23.0% were found to exceed the solar radiation protection standard, with the highest prevalence found among physical education teachers (57.4% dosimeter-days), followed by teacher aides (22.6 % dosimeter-days) and classroom teachers (18.1% dosimeter-days). In Queensland, peak outdoor exposure times of teaching staff correspond with periods of extreme UV-Index. The daily occupational H_{ICNIRP} radiant exposure standard was exceeded in all schools and in all teaching classifications.

1. Introduction

Limited data on solar ultraviolet radiation (UVR) radiant exposure in predominately indoor occupations highlights that skin cancer and eye disease are rarely considered diseases of occupation [1], yet skin cancer and chronic eye disease such as cataract, and pterygium are a probable consequence of lifetime exposure habits [2,3,4,5]. Research measuring annual and/or lifetime UVR radiant exposure and evaluating the associated risks in workers with predominantly outdoor occupations are common. Such studies include: building and construction workers [6,7,8]; Lifeguards [9]; Gardeners [10]; and Physical Education teachers [11,12]. Consequently, strong evidence is available correlating outdoor occupational radiant exposure with the incidence of non-melanocytic skin cancers. Much effort is required to reduce UVR radiant exposure in these occupations, particularly in tropical and sub-tropical regions which experience high levels of ambient solar radiation.

The intermittent sun exposure hypothesis, which places traditional indoor workers at higher risk, states that cumulative lifetime radiant exposure to solar-UVR, particularly episodes of sunburn, contribute to the risk of cutaneous melanoma in Caucasian populations [13,14,15]. Recent research by Kitchener [16] has shown there to be limited evidence of elevated risk of melanoma in Australian Navy personal compared to the general population. The findings of this research, contribute toward a recognized complexity in associating occupational exposure, whether acute, chronic or intermittent with increased melanoma skin cancer risk [17,18,19]. The Kitchener [16] study did however associate a higher risk of melanoma for Naval personnel who spent most of their working life out of direct sunlight. That intermittent exposures among workers who spend most of their time indoors cannot be excluded as a risk factor for the development of melanoma, particularly in populations exposed to high ambient levels of UVR [20,21,22] makes Classroom teachers an interesting case for studying occupational radiant exposure. The traditional role of a classroom teacher encompasses supervising children in the playground during meal breaks that generally coincide with peak ambient solar-UVR intensity. In Queensland, Australia melanoma rates are among the highest in the world [23,24,25]. Personal radiant exposures received as a consequence of the occupational requirement to be outdoors during periods of peak ambient UVR intensity highlight the potential value of collecting baseline information that may be used to advocate behavioral changes aimed at reducing melanoma risk [26,27], and reduced risk of keratinocyte cancers [28, 29].

Queensland employers are legally obliged to provide a working environment that prevents the injury or illness of workers according to the Work Health and Safety Act [30]. Solar-UVR radiant exposure, received as a consequence of the occupational requirement to provide a duty of care to Queensland school children carries the potential to cause harm to teachers due the high levels of ambient solar radiation in school playgrounds [31,32,33]. The responsibility of employers to provide a safe working environment highlighted in recent research shows that an increasing number of successful worker's compensation claims in Australia have been reported for skin damage resulting from radiant exposure to UVR in the workplace [34]. A position statement by the Cancer Council Australia [35], recommends that workplaces have a comprehensive sun protection program incorporating: assessment of UVR exposure risks, implementation of protective control measures, education and training for employees and the development of written policy. Teachers and teacher aides, as employees are bound by the policies of their designated workplaces and are therefore a population group that have the potential to adopt and follow measures aimed at reducing personal solar-UVR radiant exposure. The role teaching staff play in demonstrating sun safe behavior to school children is also recognized as one of several relevant intervention strategies actively encouraged and supported by the National 'SunSmart Schools' program which has been credited with reducing skin cancer incidence in Australia since its inception in 1988 [36,37].

We report objective measurements of the Spring-time occupational radiant exposure of primary school teachers, teacher aides, and secondary school teachers from sites in tropical (Townsville) and sub-tropical (Toowoomba) Queensland separated by 8.2 degrees of latitude. Radiant exposures are referenced relative to the Australian Radiation Protection Standard (ARPS) [38] and the erythemal action spectrum [39]. For studies in which the personal risk of erythema is of concern, the erythemally effective [39] radiant exposure is often cited rather than ARPS, although the later is more relevant in occupational radiant exposure studies. The ARPS specifically weights solar UV radiant exposure to the hazard sensitivity spectrum of the International Commission on Non-Ionizing Radiation Protection [40] for the skin and eye. According to the standard, exposure of the skin to solar radiation must not exceed a weighted daily UV radiant exposure of 30 J/m^2. Below this limit, the risk of detectable acute or delayed effects are considered extremely small [41].

2. Materials and Methods

2.1 Study Location

The northern Australian state of Queensland, located between the latitude of 10^{o}S and 28^{o}S experiences a warm tropical to sub-tropical climate, a high number of sunshine days and extreme solar UV-levels annually from September through to April in the austral spring, summer and autumn seasons. In this research solar UV radiant exposures were monitored at two sites over a wide latitudinal range in 57 workers employed in teaching roles in November toward the end of the 2014 school semester from schools located in Townsville (19.3^{o}S 146.8^{o}E) and Toowoomba (27.5^{o}S, 151.9^{o}E).

Townsville, a major regional city of 170 000 residents is located in the dry tropics along the north Queensland coast. The monthly average UV-Index range over the year in Townsville ranges from 6-13, whilst the daily maximum UV-Index is typically between 10 and 13 during November when this study was conducted [42].

Toowoomba has a similarly large regional population of 110 000 residents and is located approximately 120 km inland of the capital city of Brisbane in the south-east of the state. Elevated to an altitude of 690 m, Toowoomba experiences a temperate seasonal climate with cooler winters and a larger annual variability in the UV-Index. The monthly average peak UV-Index across the year ranges from 6-11, whilst Toowoomba's typical maximum November UV-Index ranges between 10 and 11 [43].

2.2 Monitoring Ambient solar-UVR

The University of Southern Queensland (USQ) and James Cook University (JCU) campuses, located in Townsville and Toowoomba have access to ambient erythemally weighted solar UV data monitored continuously and averaged every 10 minutes by model 501 Solar light Co (Philadelphia, PA) broadband radiometers. Instruments at both campuses are located on university building rooftop environments with unobstructed sky views. Access to the JCU radiometer was made through the Australian Radiation Protection and Nuclear Safety Authority public website [42]. The Toowoomba radiometer is maintained by the USQ solar radiation research group. Personal radiant exposure measurements expressed relative to the available ambient UVR were determined by comparison to UV-Index measurements recorded by these instruments for the period 7:00 am to 5:00 pm.

2.3 Participants

Human ethics research approvals were obtained from the University of Southern Queensland (USQ) H14REA089; The Queensland Department of Education, Training and Employment ref11/54273 and 550/27/1497; and the Catholic Education Office (Townsville Diocese) 2007-15, to approach schools and recruit volunteer study participants. Primary (prep – grade 7 in 2014; students generally 5-12 years-old) and secondary school teachers (grades 8-12 in 2014) and primary teacher aides working full-time or part-time (at least 3 days per week) were selected to participate over a period of two weeks (10 working days). Eligible participants working in teaching roles were recruited from a convenience sample of 6 government and non-government schools located within 15 km of ambient solar UV monitoring equipment located at either JCU's, Townsville campus or the USQ's, Toowoomba campus.

Each school was visited by a member of the research team and meetings were conducted with all available teaching staff to recruit volunteers. A total of 57 eligible staff provided written informed consent to participate and were issued with study information packs including a 10-day sun diary and 10 personal dosimeter badges. Participants from Townsville and Toowoomba were instructed to wear a new dosimeter daily for ten working days from 10 to 21 November, 2014. Study participants were classified as classroom teachers, outdoor Physical Education/Agriculture (PE / Ag) specialist teachers or teacher aides. The occupational radiant exposure of one school principal was also measured (Table 1).

Table 1: Characteristics of participating schools and teaching/support staff in Townsville and Toowoomba, Queensland, Australia, stratified by region.

	Total N (%)	Townsville (19.3^{o}S) N (%)	Toowoomba (27.5^{o}S) N (%)
School Characteristics (n=6)			
Government	5 (83.3)	2 (66.7)	3 (100%)
Non-Government	1 (16.7)	1 (33.3)	0
Primary	4 (66.7)	2 (66.7)	1 (33.3)
Secondary	2 (33.3)	1 (33.3)	2 (66.7)
Participant Characteristics (n=57)			
Classroom Teacher	42 (73.7)	23 (69.7)	19 (79.2)
Physical Education / Ag Teacher	7 (12.3)	2 (6.1)	5 (20.8)[a]
Teacher Aide	7 (12.3)	7 (21.2)	0
Principal	1 (1.7)	1 (3.0)	0
Full time employees	45 (79)	26 (78.8)	19 (79.2)
Part time employees	12 (21)	7 (21.2)	5 (20.8)
Government employees	50 (87.7)	26 (78.8)	24 (100)
Non-government employees	7 (12.3)	7 (21.2)	0

Footnotes:

[a] Toowoomba sample includes 1 Agriculture teacher

2.4 Sun Diaries and UV Dosimeters

The pattern of sun exposure of each of the 57 participants was monitored through the use of personal UV dosimeters and the completion of daily sun exposure diaries on scheduled workdays. Sun exposure diaries were divided into 15 minute intervals from 7:00 am to 5:00 pm. Participants were instructed to indicate periods of time outdoors of at least 5 minutes duration by proportional shading of 15 minute time intervals indicated on the sun exposure diary. Thus, '0 minutes' could be recorded as a possible daily exposure time, but brief intermittent periods of exposure of less than 5 minutes duration were not expected to be noted by the study participants. Outdoor periods were defined for the purposes of this study as those areas not inside a building and may have included open playground areas, as well as shaded and semi-shaded undercover areas including walkways and areas protected by shade sails.

Personal solar UV radiant exposures were monitored using polysulphone film (PS) dosimeters with daily radiant exposure results being expressed in dosimeter-days. The dosimeters are manufactured at the USQ Solar Radiation Research Laboratory from PS film cast to a thickness of 40 μm and adhered to flexible frames measuring 15 by 10 mm. The lightweight frames have a clear aperture of 6 mm and have been used successfully for personal radiant exposure measurements in similar studies [33,44,45].

Participants were instructed on completing daily sun diaries and the use of the dosimeters, including correct handling and storage, at the beginning of the study. Participants retained sun exposure diaries and dosimeter packs at school, attaching new dosimeters to the upper shoulder (in a horizontal plane using a safety pin) at the commencement of each working day. Dosimeters were stored by participants in supplied envelopes out of direct sunlight before leaving school. Dosimeters and diaries were collected from participants at the end of the study period. All post exposure measurements of dosimeters were conducted at the same time, two weeks after the study period to ensure consistency in the time between the end of the radiant exposure period and the absorbance measurements.

2.5 Measurement of erythemal and ICNIRP UV radiant exposure

PS film was selected for use as a dosimeter in the current study due to the physical dynamic range and suitability of PS for short term daily radiant exposure monitoring [46]. PS film experiences a measurable change in absorbency (ΔA) at 330 nm that was calibrated to the spectrally weighted UV radiant exposure. The ultraviolet radiant exposure in J/m^2 was determined by integration of the weighted irradiance with respect to time, t. Here, H_{CIE} is the erythemally effective radiant exposure according to the International Commission on Illumination [39] and H_{ICNIRP} is actinic effective radiant exposure according to the ICNIRP [40], reiterated by Directive 2006/25/EC [47] and specifically referenced by the ARPS, where

$$H_{CIE/ICNIRP} = \int_{t_1}^{t_2} E_{CIE/ICNIRP}(t)\ dt. \qquad (1)$$

$E_{CIE}(t)$ or $E_{ICNIRP}(t)$ is the weighted UV irradiance at any given time in the integral, calculated by summation in the UV waveband of the spectral UV irradiance, $E(\lambda)$ after weighting to the relevant action spectrum, $S_{CIE}(\lambda)$ [39] *or* $S_{ICNIRP}(\lambda)$ [40].

$$E_{CIE/ICNIRP} = \sum_{\lambda=280}^{400} S_{CIE/ICNIRP}(\lambda)E(\lambda)\Delta\lambda \qquad (2)$$

The H_{CIE} and H_{ICNIRP} radiant exposures were included in this research to allow direct comparison of personal radiant exposures to the erythemally effective ambient UV, and the ARPS occupational radiant exposure limit [38]. Because the change in film absorbency is dependent on the spectral characteristics of the UV source [48], separate calibrations were made for both Toowoomba and Townsville. The spectroradiometer and calibration process for film dosimeters have previously been described in detail [33,49]. Calibration characteristics for personal dosimeters traceable to the University of Southern Queensland's scanning spectroradiometer (model DTM300, Bentham Instruments, Reading UK) are included in supplementary material.

3. Results

3.1 Response

A total of 474 dosimeters were returned from the 570 dosimeters distributed to participants (83.2% response rate). Non-return of dosimeters was primarily due to the inclusion of 12 part-time staff (worked <10 days per fortnight; Table 1), in addition to unscheduled staff absences due to sickness etc, and damage/loss of a small proportion of badges (5 dosimeters).

3.2 Distribution of personal UV radiant exposures and time spent outdoors

The median H_{ICNIRP} received by all teachers across both locations was 11 J/m^2, (IQR: 2-28 J/m^2) per day. The measured personal radiant exposures were shown to approximate a log-normal distribution with the peak of the distribution coinciding with the median (Figure 1). The median self-reported exposure time determined from 480 returned sun exposure diaries was 30 minutes (IQR: 0 to 60 minutes) (Figure 2). The study medians equate to an approximate H_{ICNIRP} radiant exposure rate of 4 J/m^2 per 10 minutes, roughly the equivalent of 14 J/m^2 H_{CIE} per 10 minutes.

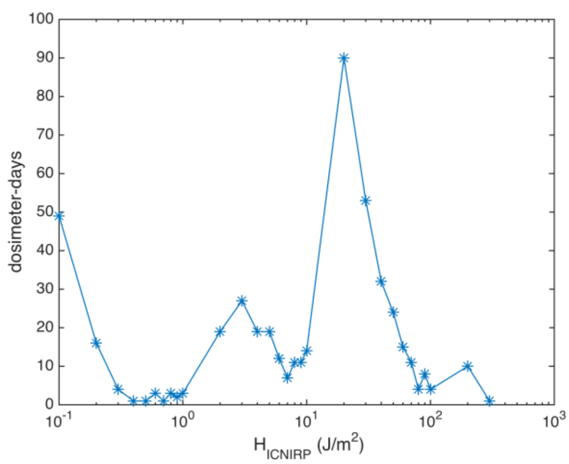

Figure 1: Distribution of ICNIRP Spring dosimeter-day radiant exposures, H_{ICNIRP} (n = 474) for all participants in Townsville and Toowoomba, Queensland, Australia.

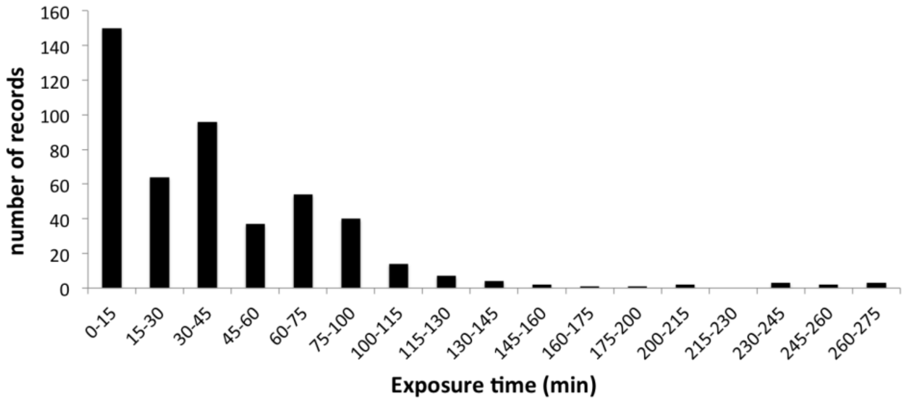

Figure 2: Distribution of self-reported daily outdoor exposure times for all participants in Townsville and Toowoomba (Queensland, Australia) over the 2-week period in late Spring (10-21 November) 2014.

A total of 49 (10.3%) H_{ICNIRP} radiant exposures fell between the range of 0 and 0.1 J/m^2. These results are representative of teaching staff that did not spend any significant periods of time outdoors during the working day. In total, 122 (25.4%) zero minute daily exposure time records were self-reported from the 480 returned sun diaries. Failure to report intermittent outdoor sun exposure times during the working day, or the contribution of stray radiant exposures received while attaching or removing dosimeters may have contributed to higher radiant exposures being recorded on self reported nil exposure time days.

3.3 Differences in UV radiant exposure by teaching role

Participant radiant exposure results, expressed as the number of dosimeter-days are summarized in Table 2. The table includes the ICNIRP and CIE calibrated personal radiant exposure. It also includes the percentage erythemal ambient radiant exposure fraction calculated with respect to the daily erythemal radiant exposure measured on a horizontal plane by the ARPANSA JCU and USQ broadband radiometers from 7:00 am to 6:00 pm.

Table 2: Distribution of the ICNIRP and erythemally effective ultraviolet radiant exposures per dosimeter-day in late Spring in Townsville and Toowoomba, Queensland, Australia, shown by study-site and teaching staff classification.

Participants	dosimeter-days N (%)	ICNIRP[a] radiant exposure (J/m^2)		Erythema radiant exposure (J/m^2)		Percentage ambient[b]	
		median	IQR	median	IQR	Median	IQR
Townsville (19.3°S)							
Classroom Teacher	185 (39.0)	11.7	4.0-26.8	40.2	11.8-95.8	0.8	0.2-1.7
PE Teacher	14 (3.0)	53.4	37.8-63.2	192.5	136.4-227.8	3.4	2.4-4.2
Teacher Aide	62 (13.1)	19.9	10.7-28.9	71.7	38.7-104.0	1.3	0.7-1.8
Principal	10 (2.1)	4.0	0.2-9.3	16.1	0.6-41.6	0.3	0.0-0.8
Toowoomba (27.5°S)							
Classroom Teacher	163 (34.4)	3.7	1.1-15.8	13.1	1.1-53.8	0.3	0.0-1.1
PE / Ag Teacher	40 (8.4)	25.7	4.7-75.4	90.4	16.7-265.5	1.7	0.3-5.2

Footnotes:

[a] ICNIRP International Commission on Non-Ionizing Radiation Protection spectral weighting function.

[b] The percentage of the radiant exposure of the dosimeters relative to the ambient is for the erythemally effective radiant exposures.

Classroom teachers recorded lower personal Spring-time UV radiant exposures than other teaching classifications. The median UV radiant exposures of classroom teachers in both Townsville and Toowoomba were less than the daily ARPS limit of 30 J/m^2 (Table 2). Comparison of these data by region revealed that the median personal H_{ICNIRP} of Toowoomba classroom teachers in late Spring was approximately three times lower than the radiant exposure received by Townsville classroom teachers. The difference in measured radiant exposures between the classroom teacher groups was statistically significant ($p < 0.0003$) for both the erythemally effective and ICNIRP radiant exposure, where comparative significance was determined in this study according to the Mann-Whitney U test.

Physical Education (PE) / Agriculture (Ag) specialist teachers in Toowoomba received approximately half the H_{ICNIRP} of the PE teachers located in Townsville ($p < 0.0709$) with a corresponding reduction in the median erythemal ambient radiant exposure fraction, decreasing from 3.4% in Townsville to 1.7% in Toowoomba. PE / Ag teacher specialists received the highest radiant exposures of all staff groups with median radiant exposures in Townsville exceeding the occupational radiant exposure limit (53.4 J/m^2, IQR: 37.8-63.2 J/m^2) and reaching 25.7 J/m^2 (IQR: 4.7-75.4 J/m^2) in Toowoomba. Comparison of median H_{ICNIRP} and H_{CIE} radiant exposures show that PE teachers received personal radiant exposures that were approximately five times higher than those recorded for classroom teachers (Table 2). Classroom teachers were the dominate study group, comprising 42 volunteer participants compared with PE / Ag specialists and Teacher Aides, making up a total of 14 participants (Table 1). Despite their small number, the 116 returned dosimeters of PE / Ag teachers and Teacher aides recorded the highest radiant exposures of all study sub groups.

Teacher aides were found to have the second highest personal radiant exposures after the PE / Ag teachers. Their median fractional ambient radiant exposure was found to be between the classroom and PE/ Ag teacher groups at 1.3% (IQR: 0.7-1.8%). The median H_{ICNIRP} radiant exposure for the teacher aides was under the ARPS at 19.9

J/m^2 (IQR: 10.7 to 28.9 J/m^2). Compared with the teacher aides, the median personal H_{ICNIRP} radiant exposure of the school principal monitored for the ten days of the November study period was well under the radiant exposure standard at 4.0 J/m^2 (IQR: 0.2-9.3 J/m^2).

3.4 Differences in radiant exposure limits by location and school characteristics

Differences in measured personal radiant exposure and self-reported outdoor exposure time varied by location (Table 3). Median H_{ICNIRP} radiant exposures for all staff groups were 15 J/m^2 (IQR: 5-29 J/m^2) and 5 J/m^2 (IQR:1-23 J/m^2) for Townsville and Toowoomba, respectively. These radiant exposures were achieved during a median self-reported total daily outdoor exposure time of 30 minutes (IQR: 0-60 minutes) for Townsville participants and 23 minutes (IQR: 0-55 minutes) for Toowoomba participants, indicating the reduction in personal H_{ICNIRP} radiant exposure between locations may be largely due to differences in exposure pattern.

The proportion of teachers exceeding the daily ARPS was consistently higher in Townsville than in Toowoomba (Table 3). A total of 24% of the participant radiant exposures in Townsville exceeded the standard compared with 21.2% of radiant exposures in the Toowoomba cohort. These proportions varied depending on teaching staff classification. Dosimeters returned from classroom teachers showed a clear trend, with 20.5% of personal radiant exposures in Townsville exceeding the limit compared with 15.3% of dosimeters returned by classroom teachers from Toowoomba. More than twice as many of the dosimeters returned by PE teachers in

Townsville (92.9%) exceeded the limit compared with those from PE / Ag teachers in Toowoomba (45%).

Table 3: Summary of dosimeter radiant exposures exceeding the ICNIRP daily radiant exposure limit N, stratified by location and school characteristics for Classroom and Physical Education (PE) / Agriculture (Ag) teacher classifications. Percentages expressed relative to *n*, the total number of radiant exposure records for each category.

Participants	Location		P value[a]	School type		P value[a]	School ownership		P value[a]
	Townsville (19.3°S) N/n (%)	Toowoomba (27.5°S) N/n (%)		Primary N/n (%)	Secondary N/n (%)		Government N/n (%)	Non-government N/n (%)	
All participants	66/271 (24.4)	43/203 (21.2)	0.0003	67 /300 (22.3)	42/174 (24.1)	0.6412	101/421 (24.0)	8/53 (15.1)	0.8140
Classroom Teacher	38/185 (20.5)	25/163 (15.3)	0.0003	39/214 (18.2)	24/134 (17.9)	0.3969	55/295 (18.6)	8/53 (15.1)	0.2117
PE/ Ag Teacher	13/14 (92.9)	18/40[b] (45)	0.0709	13/14 (92.9)	18/40 (45)	0.0709	31/54 (57.4)	-	-

Footnotes:

[a] P values are Mann-Whitney U test comparisons of ICNIRP radiant exposures for all dosimeter records (n) in each category.

[b] Toowoomba sample includes 1 Agriculture teacher

The proportion of dosimeter-days exceeding the daily ARPS occupational radiant exposure limit was similar for primary and secondary schools, with 22.3% of the dosimeters returned by primary school staff and 24.1% of the dosimeters returned by secondary school staff exceeding 30 J/m^2 H_{ICNIRP} (Table 3). The proportion of dosimeters exceeding the limit was approximately 18% for both primary and secondary classroom teachers (Table 3). The radiant exposure limit comparison between primary and secondary school PE / Ag teachers mirrored the differences by study-site, as all primary PE teachers included in the study were based in Townsville and all of the secondary PE / Ag teachers were located in Toowoomba. Comparison of personal radiant exposure with school ownership also did not reveal any significant differences although fewer non-government employees than government employees exceeded the daily occupational ARPS radiant exposure limit (Table 3). Of the 53 returned dosimeters from non-government classroom teachers, 15.1% were found to exceed the radiant exposure standard compared with 18.6% of the 295 returned dosimeters from classroom teachers employed in government schools ($p < 0.2117$).

3.5 The Radiation Protection Standard and outdoor exposure time

Collectively, 109 (23%) dosimeter records were found to exceed the ARPS radiant exposure limit of 30 J/m^2. Self-reported exposure times for staff exceeding the limit ranged from 0 to 270 minutes with a corresponding median exposure time of 60 minutes (IQR: 30-90 minutes). Teaching staff found to have personal H_{ICNIRP} radiant exposures under the daily ARPS radiant exposure limit spent between 0 and 125 minutes outdoors, with a median exposure time of 15 minutes (IQR: 0-39 minutes). Participants were not required to report exposure times less than 5 minutes, raising the possibility that actual exposure times may be slightly greater than reported here. There was however a clear statistical significance in the self-reported exposure times between the dosimeter-days exceeding the standard compared to those not exceeding the standard ($p < 0.0001$) with little observed overlap of the IQR. These results are indicative of the influence of total daily exposure time, with participants exposing themselves for longer periods being more likely to exceed the daily ARPS radiant exposure limit.

The proportion of dosimeter-days exceeding the ARPS daily radiant exposure limit was also shown to be dependent on teaching staff classification with 54.7% of dosimeter-days for PE / Ag teachers exceeding the limit compared with only 22.6% of dosimeter-days for teacher aides, 18.1% of dosimeter days for classroom teachers and 10% of dosimeter days for the school principal.

3.6 General patterns in UV radiant exposure versus exposure time

Figure 3 shows the number of self-reported teacher daily exposure times, expressed as a percentage of the number of returned sun exposure diaries against the time of day (Australian Eastern Standard Time). Importantly, the highest number of daily sun exposure records were found to occur between 11:00 am and 11:15 am, corresponding with peak ambient radiant exposure time as shown by the mean UV-Index calculated over the study period and plotted in the figure for Townsville and Toowoomba. Outdoor activity peaks were also found to occur near 1:30 pm in both locations. The timing of exposure for all participants corresponds roughly with school meal break times.

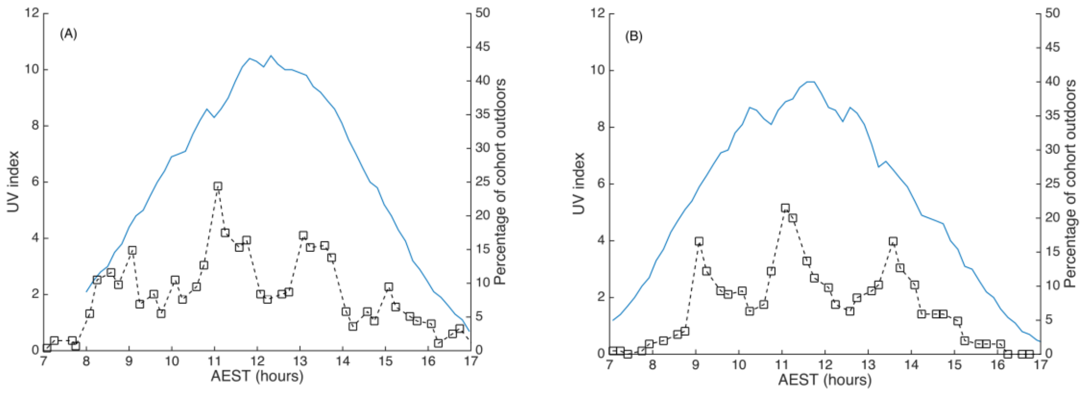

Figure 3: Average UV index and percentage of cohort outdoors expressed relative to daily Australian Eastern Standard Time (AEST) during the November study period in (A) Townsville and (B) Toowoomba, Queensland, Australia.

3.7 The influence of exposure timing

The total number of self-reported outdoor exposure times, stratified by exposure duration is provided in Table 4. Overall, 31.9% of all sun diaries reported that participants spent between 5 and 30 minutes outdoors per day. This finding was reflected by teaching classification, for classroom teachers (34.8%), and teacher aides (33.9%), with both groups spending between 5 and 30 minutes outdoors daily.

Table 4: Summary of self-reported daily outdoor exposure time records for all study participants in Townsville and Toowoomba, Queensland, Australia, stratified by teaching staff classifications.

Participants	N (%)	Daily exposure categories			
		(≤ 5 min) N (%)	(> 5 and ≤ 30 min) N (%)	(> 30 and ≤ 60 min) N (%)	(> 1 hour) N (%)
All participants	480 (100)	130 (27.1)	153 (31.9)	93 (19.4)	104 (21.7)
Classroom Teacher	353 (73.5)	96 (27.2)	123 (34.8)	68 (19.3)	66 (18.7)
PE / Ag Teacher	55 (11.5)	12 (21.8)	7 (12.7)	6 (10.9)	30 (54.5)
Teacher Aide	62 (12.9)	15 (24.2)	21 (33.9)	18 (29.0)	8 (12.9)
Principal	10 (2.1)	7 (70)	2 (20)	1 (10)	0 (0)

PE / Ag teachers were at the highest risk of exceeding the ARPS with 54.5% of this group spending more than 1 hour per day outdoors. Teacher aides were at moderate risk of exceeding the daily occupational radiant exposure limit, with 29.0% of sun diaries reporting outdoor exposure durations of between 30 to 60 minutes and 12.9% reporting outdoor exposure periods of more than 1 hour. This result is similar to that of the classroom teachers, although a slightly higher combined percentage of teacher aides were found to self-report outdoor exposure times above 30 and 60 minutes. The school principal spent the least time outdoors, with most reported outdoor exposures being less than 5 minutes per day (70% of self-reported exposure records).

The influence of daily exposure timing was considered for all participants with self-reported outdoor exposure times of up to the study median of 30 minutes. Given school hours in Queensland occur within peak UV exposure periods (between 9:00 am and 3:00 pm) and often occur when the UV-Index is 3 or greater (i.e. sun-protection required), H_{ICNIRP} radiant exposures of less than 30 minutes duration were examined between 11:00 am and 2:00 pm (highest likely H_{ICNIRP} radiant exposure risk) and for self-reported exposures up to 30 minutes received outside this time (lower H_{ICNIRP} risk) (Table 5). The likelihood of dosimeter-days exceeding the occupational radiant exposure limit was found to depend on time of day. Of all of the study participants receiving up to 30 minutes daily exposure, 18.7% exceeded the ARPS if their radiant exposure occurred exclusively between 11:00 am and 2:00 pm compared with 8.3% of study participants who received up to 30 minutes daily exposure outside of these times ($p < 0.0175$). This finding indicates that outdoor exposures up to 30 minutes duration are more likely to exceed the daily occupational radiant exposure limit of 30 J/m^2 if teachers are exposed between 11:00 am and 2:00 pm. These times correspond with meal and lunch break periods.

Table 5: Summary of H_{ICNIRP} actinic radiant exposures above or below the Australian Radiation Protection Standard of 30 J/m^2 for participants outdoors for up to 30 minutes. Data is stratified by timing of outdoor exposure.

Participants	High Risk (outdoors between 11:00 am to 2:00 pm)			Low Risk (not outdoors between 11:00 am to 2:00 pm)			P value[a]
	N (%)	Above EL	Below EL	N (%)	Above EL	Below EL	
All participants	91 (100)	17 (18.7)	74 (81.3)	36 (100)	3 (8.3)	33 (91.7)	0.0175
Classroom Teacher	77 (84.6)	15 (19.5)	62 (80.5)	30 (83.3)	3 (11.1)	27 (88.9)	0.0057
PE / Ag Teacher	4 (4.4)	1 (25)	3 (75)	2 (5.6)	0 (0)	2 (100)	0.5333
Teacher Aide	10 (11.0)	1 (10)	9 (90)	4 (11.1)	0 (0)	4 (100)	0.1419

Footnotes:

[a] P values are Mann-Whitney U test comparisons of all (N) high risk to low risk ICNIRP radiant exposures.

[b] Principal did not spend up to 30 minutes outdoors for either risk condition.

4. Discussion

Classroom teachers, as a group have not been studied extensively with reference to ICNIRP radiant exposure limits. Several studies have concluded that radiant exposures received by indoor workers receive between 0 and 4% of the available ambient UVR [50,51], however these studies do not weight measured radiant exposures specifically to the ICNIRP [40] action spectrum. To ascertain UVR radiant exposure risk in the workplace, internationally recognized radiant exposure safety standards should be applied. The ICNIRP standard applied here and reiterated in the ARPS [38] has determined specifically the number of employees exceeding recommended radiant exposure limits. Of the 23.0% of teaching staff found to receive radiant exposures over the limit, most were PE / Ag specialist teachers. This did not however exclude classroom teachers or teacher aides from exceeding occupational standards.

Collectively, study participants were found to receive approximately 4 J/m^2 per 10 minutes of outdoor radiant exposure. Based on this exposure rate, the teachers in this study would be expected to exceed the ARPS of 30 J/m^2 in 70 to 80 minutes outdoor exposure time. Given the H_{ICNIRP} to H_{CIE} varies by a factor of 3 to 4 for most periods of the day outside twilight hours and low solar elevations [7] and given a likely

November daily peak UV-Index of 10 (0.25 W/m^2 H_{CIE}), the expected ambient H_{ICNIRP} under these conditions would roughly correspond to 0.07 W/m^2. Under these conditions the ARPS, weighted with respect to the H_{ICNIRP} would be exceeded in a little over 7 minutes (429 seconds). The study median outdoor exposure times for those participants found to exceed the ARPS was 60 minutes. These results reflect the protective (indoor or shade seeking) exposure habits of the group as a whole. This group consisted mainly of classroom teachers (73.7%).

All teachers that spent more than 2 hours outside daily exceeded the occupational radiant exposure standard. The study median radiant exposure time of participants over the ARPS was 60 minutes. A statistically significant number of daily exposure records were found to exceed the ARPS limit in less than 30 minutes for those teachers who self-reported outdoor radiant exposure times exclusively between 11:00 am and 2:00 pm. A significant point of difference in the current study to other occupational groups is that whereas meal times represent times of reduced UV radiant exposure in other outdoor occupations [8], they represent periods of increased radiant exposure for school teaching staff. Teachers employed in Queensland are entitled to 30 minutes daily for meal breaks between 11:30 am and 2:00 pm although no limit is given to the number of outdoor playground duties a teacher may be required to supervise [52,53]. The requirement of meal breaks to be taken between 11:30 am and 2:00 pm is likely to be a contributing factor to the high number of playground supervisions (and therefore outdoor exposures) observed between 11:00 am and 1:30 pm. Using our study sample as a guide, teachers performing a single, hourly yard duty on any one day of the week would be at significant risk of exceeding the daily occupational radiant exposure limit.

Some differences in the number of participants exceeding the ARPS were found between different participant classifications. PE / Ag teachers were at particular risk, spending for the most part, more than 30 minutes daily outdoors. This result is a likely consequence of playground supervision requirements for PE / Ag teachers coupled with the necessity to spend a greater proportion of the day outdoors supervising sport or agriculture lessons. Removal of the requirement of PE / Ag teachers to conduct playground duty during the working week would clearly contribute to a reduction in occupational radiant exposure risk for this group and would make an important contribution to school workplace health and safety policies.

A new study group, not previously investigated in UV exposure research were the teacher aides. This participant group recorded the second highest H_{ICNIRP} radiant exposure after the PE / Ag specialist teachers. In Queensland, it is currently a requirement of teacher aides to supervise children during breaks [54]. This does not preclude supervision during meal breaks. Given that most of the teacher aides in our study were found to be outside for greater than 30 minutes indicates that the children they supervise on a day-to-day basis are also likely to be spending this amount of time outdoors. This makes this particular group an interesting cohort to follow in future studies.

Difference in geographical latitude between Townsville and Toowoomba could not be isolated as an exclusive factor associated with the likelihood of exceeding the occupational radiant exposure standard. That personal radiant exposures in tropical north Queensland were higher than those measured in southern Queensland for all teaching classifications is likely to be attributed to behavior differences and total daily radiant exposure time variation between groups. The relative ambient radiant exposure fractions of classroom teachers (Table 1) support the notion that participants in the Toowoomba group were more likely to stay indoors under comparatively similar ambient conditions, with the UV-Index reaching a maximum daily average of 10.5 in Townsville and 9.6 in Toowoomba during the study period. Although low ambient exposure fractions are consistent with the findings of research reported by other authors, the findings of our study highlight that occupational radiant exposures received by teaching staff occur in or near lunch break periods. This places staff required to supervise children at these times at greater risk of exceeding occupational radiant exposure standards.

5. Conclusions

The findings of the current study provide baseline information on occupational radiant exposures and behavior patterns of teachers from schools located in a warm, and high ambient UV climate. This information is relevant to teaching staff working in tropical and subtropical locations and may by indicative of radiant exposure patterns likely to be observed by staff working in an increasingly warmer and variable global climate.

A clear strategy that would have a measureable impact on reducing the number of staff exceeding the ARPS would involve reducing the total amount of time spent outdoors. This strategy, along with sun exposure minimization, improved identification and sun exposure awareness training for workers, and the mandatory use of personal protective equipment will assist in guiding the development of more comprehensive school policies that aim to reduce the potential of staff to exceed recommended radiant exposure limits [55]. Given that most teachers were found to be entering outdoor environments during peak UV-Index periods, strategies which aim to minimize radiant exposure during school break times are the most likely to have a positive impact on improving the occupational health outcomes of Queensland teachers.

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