Title: Levels of occupational exposure to solar ultraviolet radiation in Vancouver, Canada

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Abstract

Introduction

Outdoor workers are at high risk of exposure to solar ultraviolet radiation (UVR), a known human carcinogen. In Canada no objective measures of UVR exposure are available for occupational settings.

Methods

The Outdoor Workers Project collected UVR exposure data among outdoor workers in Vancouver, Canada during the summer of 2013. Objective measures of exposure were taken for one week using calibrated electronic UVR dosimeters. Additional data was collected from workers on skin cancer risk factors, family history of skin cancer, and job type; as well as meteorological data for sampling days. Marginal models were constructed to examine the worker, job and meteorological determinants of UVR exposure levels, as measured in Standard Erythmal Dose (SED).

Results

Seventy-eight workers were recruited, of which seventy-three had at least one day of measured UVR exposure for this analysis. Participants were mostly male, young and Caucasian. Mean exposure (corrected for repeated measures) was 1.08 SED. Exposure measures were highly variable even in the same workplace, ranging from 0.01 SED to 19.2 SED. Younger age, working in land-based construction, and sunnier weather forecasts led to higher levels of UVR exposure.

Conclusions

Exposure levels capable of causing sunburn were common in the present study of outdoor workers, in a location not typically associated with high sun exposure.

Introduction

Solar ultraviolet radiation (UVR) is a known human carcinogen with sufficient evidence for melanoma and non-melanoma skin cancers (International Agency for Research on Cancer, 2012). Non-melanoma skin cancer (NMSC, including squamous and basal cell carcinoma) in particular is of concern for outdoor workers, a group at risk of high cumulative exposure to solar UVR (Bauer, Diepgen, and Schmitt 2011; Schmitt et al. 2011). In Canada, NMSC is the most commonly diagnosed malignancy (Canadian Cancer Society's Steering Committee 2015), and approximately 1.5 million Canadians are at risk of solar UVR exposure at work (Peters, Nicol, and Demers 2012). The relationship between outdoor work and NMSC risk is clear, and the approximate doubling of cancer risk seen in meta-analyses is likely an underestimate due to exposure misclassification (i.e. sun-exposed people being classified as unexposed, and crude exposure assessments in general) (Schmitt et al. 2011).

Most studies of occupational UVR exposure use self-report or time spent out of doors as their exposure metric (Glanz et al. 2008). However, personal exposure measurements show wide variability in UVR dose, and ambient environmental factors contribute to this variability (Dadvand et al. 2011; Gies and Wright 2003; Gies, Glanz, et al. 2009; Thieden, Philipsen, et al. 2005). It is likely that the lack of objective measurements of solar UVR exposure has contributed to the complicated epidemiology of skin cancer with respect to timing of exposure

as well as pattern, and that objective measures of the hazard could lead to better estimates of the dose-response relationship between UVR exposure and skin cancers (Milon et al. 2014). Personal dosimetry for outdoor workers has not previously been done in Canada.

The objective of this study was to objectively measure personal solar UVR exposure among a convenience sample of outdoor workers in Vancouver, Canada, and to examine whether personal, work, or meteorological factors are important determinants of exposure levels. This data is important in Canada for providing preliminary evidence of exposure levels among a high-risk group (primarily construction workers during summer hours) and for demonstrating the feasibility of using UVR dosimetry across a variety of settings, including heavy industrial locations, in addition to providing valuable study design recommendations for future studies. As such the findings from this study are considered exploratory but none-the-less necessary inputs for advancing the investigation of occupational exposure to UVR within the Canadian environment.

Methods

Study design

The Outdoor Workers Project (OWP) was a cross-sectional study that took place in the summer of 2013 (data collection from July to September) in the greater Vancouver, British Columbia area. Sampling was scheduled during the summer months as a high exposure period within the Canadian context. Workers wore an electronic UVR dosimeter badge for approximately five working days, and filled out an activity diary once per hour during measurement days. The selection of the sampling period was done in consultation with the workplaces to maximize participation and to ensure that workers were scheduled to work for five consecutive days (i.e. avoiding holidays or off-shift periods). Workers completed a questionnaire that provided data on demographics, skin cancer risk factors, job characteristics, and sun protection behaviours at work as well as in leisure time. In addition, weather forecasts including UV Index were recorded from Environment Canada for each sampling day. The current study focuses on the exposure measurements from the UVR dosimeter badges.

Study sample

The study used a purposeful sample to recruit construction workers, with the addition of a convenience sample intended to recruit other workers with high exposures in the greater Vancouver area during the summer months. Participants in the Outdoor Workers Project were recruited via building trade unions and by approaching companies with outdoor operations via health and safety staff. Several workers also learned about the study via word-of-mouth and were invited to participate; these were mainly non-construction workers (with a few exceptions) and were not turned away from participation due to the exploratory nature of the study (convenience sample recruits). Eligibility was met by workers 18 years of age or older and who spent at least part of an average workday outdoors. The study protocol was approved by the University of British Columbia Research Ethics Board (certificate H11-01272).

Data collection

Solar UVR exposure data was collected using personal electronic dosimeters (Mark II). The dosimeters' functionality is described elsewhere (Allen and McKenzie 2005), but briefly, UVR is detected using aluminum-gallium-nitride photodiodes, which have a spectral response that closely matches the erythral (skin burning) action spectrum for human skin (McKinlay and Diffey 1987). The dosimeters contain a processor with an analog converter allowing the reading of UV irradiance at pre-specified sampling intervals (Sherman 2012). The analog measurements were converted to UV Index via side-by-side calibration with a Brewer Spectrophotometer (Environment Canada 2014). The spectrophotometer measures spectral UV irradiation (between 295 and 325 nanometers) every 10 to 20 minutes during daylight hours.

The dosimeters are wireless and data-logging, and were programmed to take a measurement once per minute between the hours of 8AM and 5PM. Each per-minute measurement was converted to a UV Index measure via the calibration curve, and the standard erythral dose (SED) for each day was calculated by adding each per-minute SED by day (Mahe et al. 2013), as per equations [1] and [2]:

$$[1] \quad SED_{day} = \sum_{8AM-5PM} [SED_{minute}]$$

$$[2] \quad SED_{minute} = \frac{[(UVIndex_{minute}) * (0.025 \text{ W/m}^2) * (60 \text{ seconds/minute})]}{100 \text{ Joules/m}^2}$$

where SED_{day} is the Standard Erythral Dose per work day in Joules/m²; $UV Index_{minute}$ is the UV Index (unitless) measured from the dosimeter badge per minute; 0.025 W/m² is the standard unit for solar irradiance per unit of UV Index; and 1 Joule = 1 Watt / second.

Workers were asked to don their dosimeters each morning of the sampling week and wear them for the full workday. The dosimeters can be worn on a wrist band, pinned to a lapel, or placed on a hardhat; workers were given the option of any placement they preferred.

Meteorological conditions were noted each morning of the study from the Environment Canada forecast for general weather and forecasted maximum UV Index (Environment Canada et al. 2014). In addition, the actual maximum UV Index was noted from the Brewer Spectrophotometer for each day.

Variables and statistical analyses

Questionnaire variables on demographics and risk factors for skin cancer (age, sex, education, reporting more than one painful or blistering childhood sunburn, family history of skin cancer, skin type (Fitzpatrick scale) (Fitzpatrick 1988), grouped as fair [type I and II], medium [type III] and dark [type IV and V]), eye colour (light [blue, grey, or green] or dark [hazel and darker]), hair colour ((blonde/red or brown/darker)) and job information were included to explore differences in UVR exposure levels among the study participants. Jobs were categorized into horticultural, land-based construction (e.g. road building), and marine-based construction (e.g.

dock building), and length of time at the current job was also included as a potential exposure variable. The classification into job groups also took into account the difference in sampling strategy for those workers recruited purposefully versus those who were recruited via word-of-mouth, since these workers were largely non-construction workers. Time spent outdoors between the hours of 8AM and 5PM was reported via the daily task diaries.

In addition to examining the daily SED values, these were compared to the available maximum SED for each calendar day, as calculated from measurements taken at the Brewer Spectrophotometer. In order to calculate the maximum daily ambient UVR, UV Index data from the Brewer were downloaded for each study day. The Brewer measures UV Index once every 10 to 20 minutes, so the SED accumulated per minute was calculated by integrating forward in time, assuming that the UV Index remained the same as the previous measure until the next measure occurred. SED_{max} was then calculated for each study day by adding per-minute values, as in the calculation of individual exposures from the dosimeters (see equations [1] and [2]). Each person's SED per day was compared to the dose available for that day as a percentage of maximum ($SED_{\%max}$).

Data for a day was removed when it indicated that the worker had not donned their badge, or that it was covered or oriented incorrectly (i.e. an 'idle' day). Days were considered idle when they had an $SED_{\%max}$ of less than the 5th percentile, calculated separately by the reported number of hours spent outside at work between 10AM and 4PM. In this way, lower $SED_{\%max}$ values were allowed to remain in as "true" samples if workers reported spending shorter times out of doors.

SAS PROC MIXED (SAS Institute 2010) (version 9.3) was used for analyses to control for repeated measures per person and per calendar day. Differences in the mean SED_{day} and $SED_{\%max}$ between groups were tested (after natural log transformation) using the F statistic. PROC MIXED was also used to create two separate marginal models examining the relationships between job, weather and demographic variables and 1) the natural-log-transformed standard erythemal dose (SED_{day}); and 2) the log-transformed $SED_{\%max}$. A manual backwards stepwise regression method was used. Potential explanatory variables initially considered for entry into the models were demographic (sex, age, race), training and work characteristics (education, job group, job tenure), and weather forecast (grouped into sunny, mixed, or cloudy sampling work days). The best fit model was chosen by removing the non-significant variables (p-value of less than 0.20) one by one until the best fitting model was found using the Akaike information criterion (AIC). Age and job tenure were highly correlated, so they were modeled separately.

Results

Demographics and skin cancer risk factors

In total, seventy-eight outdoor workers were recruited for participation in the Outdoor Workers Project. Seventy-three workers were included in the current analysis; two were excluded due to lost dosimeter badges, one due to dosimeter malfunction, one for not completing the questionnaire, and one because all sampled dates were deemed 'idle'.

There were initially 336 exposure days collected among the seventy-three included participants; 18 days were determined to be “idle” days where participants were unlikely to have donned their badges, leaving a total of 318 included exposure days, and 73 participants with at least one active sampling day. In total, 40 calendar days were represented.

Participants were mostly male (96%), young (mean 38 years), and Caucasian (96%) (Table 1). Despite only 15% of the workers reporting very fair or fair skin, most workers (73%) reported at least one sunburn the previous summer. The majority of participants worked in construction-related industries; 19% worked in horticultural or non-construction industries (Table 1).

Meteorological data

The data collection period (July to September 2013) was mostly sunny (25 of 40 days) and warm (mean 23°C, range 19 to 29 °C). Measures of the daily forecasted maximum UV Index and temperature are shown in Table 2, as are the actual daily maximum UV Indexes, and the calculated maximum dose available per day in SED. Agreement between the predicted and actual UV Index measures was very high (Pearson correlation coefficient 0.89, $p < 0.0001$). Though sunny days are relatively common in the Vancouver summer, records for low rainfall and hotter days were both set during the study period (Huffington Post 2013; Judd 2013).

Table 1: Demographic and risk factor data for exposure monitoring in the Outdoor Workers Project

Variable	n (%)
Sex	
Male	70 (96)
Female	3 (4)
Age	
Mean, range	38.3 (18 – 69)
Education	
High school or equivalent, or less	21 (29)
Some college, trade school, or university	23 (32)
Completed college, trade, or university	25 (34)
Prefer not to say	4 (5)
Race	
Caucasian	70 (96)
Other	3 (4)
Skin type	
I and II (very fair and fair)	11 (15)
III (white to olive)	40 (55)
IV - VI (olive to brown and darker)	22 (30)
Eye colour	
Light blue, grey, or green	48 (66)
Hazel or darker	25 (34)
Hair colour	
Red or blonde	8 (11)
Light brown or darker	65 (89)
Number of sunburns in the previous summer	

None	20 (27)
1	32 (44)
2+	21 (29)
More than 1 severe childhood sunburn?	
Yes	42 (58)
No	31 (42)
Family history of skin cancer	
Yes	8 (11)
No or don't know	65 (89)
Job group	
Marine construction	31 (43)
Land-based construction	28 (38)
Horticultural/non-construction	14 (19)
Time at current job	
Mean, range	11.9 (0.25 – 38)

Daily high temperatures were also correlated with UV Index variables (Pearson correlations of 0.50 and 0.51 for the predicted UVI and actual UVI, p values 0.001 and 0.0008, respectively), but the correlation was less strong due to several relatively cool days with high UV Index values. The daily available UV dose showed that available UV dose was more than double on sunny compared to cloudy days.

Table 2: Meteorological results by daily weather forecast (calendar days in study = 40 between July and September, 2013)

	n days (%)	Forecasted maximum UVI (mean, sd)	Actual maximum UVI (mean, sd)	Maximum available UV dose (SED)	Maximum forecasted temperature (mean, sd)
Forecast					
Sunny	25 (63)	7.1 (0.67)	6.9 (0.78)	36.6 (5.6)	23.4°C (2.1)
Mixed sun/cloud	8 (20)	5.0 (0.76)	4.9 (0.99)	21.0 (6.6)	21.3°C (1.2)
Cloudy	7 (17)	3.1 (1.80)	4.1 (1.70)	16.9 (8.1)	21.0°C (1.5)

Ultraviolet radiation (UVR) dosimetry results

Both exposure variables (SED_{day} and $SED_{\%max}$) were log-normally distributed (see Figure 1 for a histogram of SED_{DAY} values); the two variables were also highly correlated (Pearson correlation coefficient of 0.98), which suggests that the available ambient UVR was a major contributor to exposure level. Results are shown in Table 3, including uncorrected means (which discounts repeated measures) and corrected means with associated p-values from one predictor-variable marginal models. The overall uncorrected arithmetic mean of daily UV measures ($n=318$) was 2.39 Standard Erythemal Doses (SED), and 6.84% of the total UV available per day (Table 3). The maximum recorded SED_{day} was over 19; that same measurement accounted for 53% of available UV on the day it was measured (meaning the worker received over 50% of the total available UVR on that day).

Figure 1: Distribution of ultraviolet radiation dose measurements per day in the Outdoor Workers Project (n=318 measurements). SED_{DAY} = standard erythemal dose per day.

Daily mean exposure was 1.08 Standard Erythemal Doses (SED_{day}), and 3.3% of the available daily maximum UV dose. None of the demographic or personal risk factors had a statistically significant relationship with either SED_{day} or SED_{%max}.

UV exposure differed by job group, with horticultural/non-construction workers receiving less than half the average SED_{day} doses of the construction workers (Table 3). The most important factor considered was the daily forecasted weather, which was strongly statistically significant and showed a clear pattern of higher SED measures with increasing sunny weather (Table 3).

Table 3: Ultraviolet radiation (UVR) monitoring results for daily SED measurements and % of maximum available UVR

Uncorrected for repeated measures	SED _{day} [*]	Range	SED _{%max} [†]	Range
<i>n=318 measurements</i>				
Arithmetic mean (SD)	2.39 (2.86)	0.01 – 19.2	6.84 (7.85)	0.03 – 53.3
Geometric mean (GSD)	1.18 (3.84)		3.63 (3.51)	
Corrected for repeated date and subject ¹	SED _{day} (SE)	p-value	SED _{%max} (SE)	p-value
Mean				
All subjects (n=73)	1.08 (1.14)	-	3.33 (1.13)	-
Sex				
Male (n=70)	1.04 (1.15)	0.161	3.22 (1.13)	0.190
Female (n=3)	2.69 (1.93)		7.34 (1.84)	
Age				
All subjects (β, SE)	-0.015 (0.011)	0.169	-0.017	0.086
Race				
Caucasian (n=70)	1.06 (1.15)	0.495	3.27 (1.14)	0.482

Other (n=3)	1.70 (1.97)		5.14 (1.87)	
Skin type				
I and II (very fair and fair) (n=11)	1.05 (1.04)	0.124	3.17 (1.37)	0.165
III (white to olive) (n=40)	0.87 (1.20)		2.78 (1.18)	
IV - VI (olive to brown and darker) (n=22)	1.62 (1.27)		4.75 (1.25)	
Job group				
Marine construction (n=31)	1.28 (1.22)	0.021	3.61 (1.20)	0.071
Land-based construction (n=28)	1.30 (1.23)		4.07 (1.22)	
Horticultural/non-construction (n=14)	0.50 (1.35)		1.86 (1.32)	
Placement of badge				
Lapel (n=62)	1.05 (1.16)	0.519	3.26 (1.15)	0.431
Hard hat (n=5)	1.87 (1.68)		5.79 (1.61)	
Wrist band (n=6)	0.90 (1.60)		2.60 (1.54)	
Forecasted weather				
Cloudy (n=7)	0.24 (1.36)	<0.0001	1.06 (1.34)	0.001
Mixed (n=8)	0.74 (1.19)		2.97 (1.18)	
Sunny (n=25)	1.27 (1.14)		3.63 (1.13)	

* SED_{day} is an erythemally-weighted measure of radiant exposure per work day. 1 SED=100 Joules/m²

† $SED\%_{max}$ is the percent of total available SED received per day (i.e. $SED_{day} \div SED_{max} \times 100$).

¹Corrected: results are estimates from a marginal model containing the variable noted in the leftmost column as the only predictor, controlling for repeated subject and calendar date.

Estimated coefficients for the two separate marginal models (one for SED_{day} and one for $SED\%_{max}$) are shown in Table 4. Since the log-transformed SED_{day} and $SED\%_{max}$ values were used, final values from the models should be exponentiated to obtain an interpretable estimate (worked example shown below). In the model examining determinants of SED_{day} , job group, age, and the general weather forecast remained in the model. In the model examining predictors of $SED\%_{max}$, similar results were found.

Table 4 Model results: predictors of SED_{day} (Standard Erythema Dose per day) and $SED\%_{max}$ (Standard Erythema Dose as a percentage of total available ultraviolet radiation)

Predictor	SED _{day} model*		SED% _{max} model*	
	Coefficient (SE)	p-value	Coefficient (SE)	p-value
Intercept	0.36 (0.46)	0.429	1.56 (0.45)	0.0009
Job group				
Marine construction	0.66 (0.34)	0.06	0.50 (0.33)	0.1356
Land-based construction	0.76 (0.34)	0.03	0.64 (0.33)	0.0585
Horticultural/non-construction	0	-	0	-
Forecast				
Cloudy	-1.63 (0.30)	<0.0001	-1.19 (0.29)	0.0002
Mixed	-0.54 (0.15)	0.0008	-0.20 (0.14)	0.1622
Sunny	0	-	0	-
Age				
Continuous variable	-0.02 (0.01)	0.061	-0.02 (0.01)	0.0455

**Demographic, work and environment variables were offered to multivariable models, but only variables that remained important in the model are presented here.*

These models can be interpreted by considering the equations [3] and [5] for the SED_{day} model and equations [4] and [6] for the SED_{%max} model, as shown below:

$$\begin{aligned} [3] \ln\text{-SED}_{\text{day}_i} &= -0.02(\text{age})_i + \beta_2(\text{forecast})_i + \beta_3(\text{job group})_i + 0.36 \\ [4] \ln\text{-SED}_{\% \text{max}_i} &= -0.02(\text{age})_i + \beta_2(\text{forecast})_i + \beta_3(\text{job group})_i + 1.56 \end{aligned}$$

So for example, for worker i, who is a 45 year old marine construction worker on a sunny day, we have:

$$\begin{aligned} [5] \ln\text{-SED}_{\text{day}} &= -0.02(45) + [0(\text{sunny}=1) + 0.66(\text{marine}=1)] + 0.36 \\ &= -0.9 + [0 + 0.66] + 0.36 \\ &= 0.12 \\ \text{SED}_{\text{day}} &= \exp(0.12) \\ \text{SED}_{\text{day}} &= \mathbf{1.13 \text{ SED}} \\ [6] \ln\text{-SED}_{\% \text{max}} &= -0.02(45) + [0(\text{sunny}=1)] + 0.50(\text{marine}=1)] + 1.56 \\ &= -0.9 + [0 + 0.50] + 1.56 \\ &= 0.71 \\ \text{SED}_{\% \text{max}} &= \exp(0.71) \\ \text{SED}_{\% \text{max}} &= \mathbf{2.03\%} \end{aligned}$$

Worker i could thus expect to receive a daily dose of about 1 SED, and 2% of the available UV dose for that hypothetical day.

A variety of categorizations for job were attempted, however there were several categories with very few workers, so the broad categorization of marine construction, land construction and horticultural work were retained. This categorization also reflected differences in recruitment strategy.

Discussion

The Outdoor Workers Project was the first study to objectively measure real-time, personal exposure to solar UVR among a high-risk occupational group in Canada. It is important to collect dosimetry data for outdoor workers' exposure to solar UVR from all over the world in order to validate models and compare risks due to the extremely high exposure variability found both within and between locations. Participants in the Outdoor Workers Project were exposed to highly variable amounts of solar UVR, even under similar ambient conditions. Exposure ranged from 0.01 SED to 19.2 (0.03% to 53% of total available UVR). These results are consistent with results from countries at comparable latitudes. For example, a study of gardening workers in Denmark and Ireland showed mean daily SED values of 0.97 in Ireland and 1.6 SED in Denmark,

though the range in exposure was not as high; maximum values of 2.7 and 3.8 in Ireland and Denmark, respectively, were reported (Thieden, Collins, et al. 2005). However, this was likely driven both by the available ambient UVR in Vancouver during the study, as well as difference in tasks between gardeners and workers in the current study. The mean ambient SED in the current study was 29.9 SED, while it was only 17.8 in Copenhagen and 19.1 in Dublin. Workers in the study by Thieden and colleagues also took shady lunch breaks, which did not happen consistently in the current study. Values recorded in the present study were lower than has been seen in studies of lifeguards in the United States (median values depending on city ranged from 1.7 SED in Portland, Oregon, to 6.2 in Omaha, Nebraska; note that these workers only spent an average of 4 hours outdoors)(Gies, Glanz, et al. 2009). Exposures in construction workers in Australia are much higher, with median values of around 5 to 10, but as high as 32 SED in a single day (Gies and Wright 2003). A recent Spanish study found median values of around 3 SED per day (compared to approximately 1 SED in the current study), which is within an expected realm, given the latitude and weather in Spain as compared to Vancouver (Serrano et al. 2014). Other studies in Australia and New Zealand (where most measurement studies have been done) have found exposure levels that are much higher (an order of magnitude), but again this is very likely due to higher ambient exposure to solar UVR in those countries (Gies, Roy, and Toomey 1995; Gies and Wright 2003; Gies, Glanz, et al. 2009; Gies, Watzl, et al. 2009; Hammond, Reeder, and Gray 2009). While there are no explicit occupational exposure limits for solar UVR exposure in Canada, international regulations and guidelines exist and are based on the limit of 30 Joules/square meter, divided by the effective irradiance. For acute skin damage, the ICNIRP guideline for the maximum efficient radiant exposure equates to approximately 1 to 1.3 SED (ICNIRP 2010). Considered in an alternative way, at a UV Index of 8 (typical for sunny days in this study), the exposure limit would be exceeded in about 10 minutes (Gies, Glanz, et al. 2009).

Ambient UVR exposure depends on many factors, including latitude, weather (cloud cover), altitude, season, time of day, and surface reflection (Worswick, Cockburn, and Peng 2008). Personal exposure depends on these factors in addition to time spent outdoors (frequency of exposure), timing of exposure (intensity), work tasks performed, and shade availability and use (Dadvand et al. 2011; Diffey 2008; Thieden et al. 2004), as well as other sun protective behaviours. Therefore it is not surprising that wide variation in exposure levels occur even under identical atmospheric conditions. Indeed, weather conditions had a clear impact on exposure levels in the current study, with sunnier days leading to higher exposure. Information on tasks performed each day was collected (so that work-related behaviours could be assessed as contributors to variability in measured doses), but the data was not usable as this information was not recorded reliably. For example, many workers were observed completing their task diaries on the last day of the study, and simplified their tasks to one or two that they performed all week. Future studies with a particular interest in task-specific variability should account for this by either having someone else record tasks, or designing the study in a workplace setting where workers are allotted more time to complete task diaries. Alternatively, the use of electronic survey devices that are quick and easy to fill out, with the potential for reminders to be sent could be investigated in future studies to improve task-based data collection.

Broad job title was a determinant of exposure in the final model for SED_{day} , with the land-based construction workers having a significantly higher dose than those working in horticulture. In an Australian study of construction workers, Gies and Wright also found wide variability between different job titles, with cabinet makers, painters and construction inspectors receiving about $1/10^{th}$ the median UVR exposure of pavers or machine operators (Gies and Wright 2003). Interestingly, workers in the previous study had higher exposure than in the current outdoor workers study (and were also measured for less time), although the general exposure pattern by job was similar, with pavers, traffic controllers, and riggers having higher exposure than supervisory or carpentry workers (data not shown).

It is difficult to compare directly the actual measured exposure levels in the OWP and other studies from around the world. Reasons for this include a lack of standardized measurement methods, differences in study design, and the wide variety of environmental and location-specific contributors to daily UVR exposure in outdoor workers; however this study provides the first Canadian values for future comparison with other more local studies (i.e. in North America).

Older age was related to lower sun exposure in the $SED_{\%max}$ model (marginally so in the SED_{day} model). This is typical of other studies, including in the Canadian national sun safety survey from 2006; 49% of outdoor workers aged 16-24 reported spending at least 4 hours per day in the sun, and this drops to 37% in workers over the age of 45 (Marrett, Pichora, and Costa 2010). In the current study, older workers more often had supervisory roles that required more office or in-vehicle time, leading to this reduction in their exposure levels.

There are limitations to this analysis that should be noted. Firstly, it would be useful to address the impact of badge placement in future studies, either by requiring specific placements by worker to have a more balanced design, or simply by increasing the sample size. Further to that point, the sample size was indeed small and limited to one geographic location. In order to properly characterize solar UVR exposure in outdoor workers in Canada, a larger study would be required, but the current study demonstrates the feasibility of such an undertaking. In addition, exposures in some other parts of the country are likely to be higher due to higher available ambient UVR in the summer months. In this way, results from this study should not be extrapolated beyond construction and horticultural workers in the Vancouver area, and even then, could be underestimated due to many workers in the study finishing work in the early to mid-afternoon. However, these industries often have earlier start schedules, and so other workers in the area working for different companies very likely have similar exposure levels to those in the current study.

Summertime-only exposure data was collected in this study because this is the time of year in Canada where risk of sunburn is highest, and thus is the time when skin cancer prevention work often takes place. Indeed, in the Canadian winter, UVR exposure is too low to even allow the endogenous production of vitamin D, leading physicians to recommend supplementation in the diet (Health Canada 2012). Since Canadian winters are cold, workers are also likely to be more covered up, and the daylight hours are shorter. A significant contribution to the UVR dosimetry

literature could be made by considering year-round exposure in Canadian outdoor working populations, with a special consideration of the potential for exposure in mountain/snow-covered environments.

The dosimeter badges used in this study are only just gaining in popularity, and remain relatively new. Most previous dosimetry studies have used polysulphone badges rather than electronic ones (or different electronic ones), and this may hinder direct comparisons with other studies. However, the badges rely on the same principles for measurement and were calibrated with similar instruments and weighting functions, and the results were in the range of what might be expected, even given geographic differences between Canada and other locations. In several Danish studies with comparable environments to Canada, exposure levels were very similar, ranging from daily SED measures of 0.75 to 3.8 (Thieden et al. 2004; Thieden, Collins, et al. 2005; Thieden, Philipsen, et al. 2005).

There were several instances during the course of the sampling where badges were partially covered by clothing, or flipped to point downward rather than straight out from the lapel. The researcher was able to re-position the badges when these situations were observed, but further instructions with reminders should be provided to participants to reduce this measurement issue. The poor quality of data collected in the task diaries meant that no correction for posture was possible (since we know exposure would be underestimated if a worker was bent over, for example). As a result, it is likely that the mean exposure values measured in the Outdoor Workers Project were underestimated, and that the problem of solar UVR exposure among workers in Canada's west coast could be higher.

Based on the current data, outdoor workers in Canada could be at risk of significant exposure to solar UVR in the summer months. The mean exposure levels found were over 1.0 SED, which is capable of increasing the risk of skin cancer, and a small number of study participants routinely received UVR doses that were much higher. Exposure was highest for those working in construction as compared to horticultural professions, higher on sunnier days, and higher for younger workers. This has important implications for prevention initiatives designed to reduce the risk of skin cancer in outdoor workers.

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