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Published in:
Photochemistry and Photobiology

DOI:
10.1111/php.12920

Publication date:
2018

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Grandahl, K., Eriksen, P., Ibler, K. S., Bonde, J. P., & Mortensen, O. S. (2018). Measurements of Solar Ultraviolet Radiation Exposure at Work and at Leisure in Danish Workers. *Photochemistry and Photobiology*, *94*(4), 807-814. https://doi.org/10.1111/php.12920

Photochemistry and Photobiology, 2018, 94: 807–814

Measurements of Solar Ultraviolet Radiation Exposure at Work and at Leisure in Danish Workers

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Received 8 February 2018, accepted 16 March 2018, DOI: 10.1111/php.12920

ABSTRACT

Exposure to solar ultraviolet radiation is the main cause of skin cancer and may well present an occupational health and safety problem. In Denmark, skin cancer is a common disease in the general population, but detailed data on solar ultraviolet radiation exposure among outdoor workers are lacking. The aim of this study was to provide objective measurements of solar ultraviolet radiation exposure on working days and at leisure and compare levels of exposure between groups of mainly outdoor, equal-parts-outdoor-and-indoor and indoor workers. To this end, UV-B dosimeters with an aluminum gallium nitride (AlGaN) photodiode detector were used to measure the solar ultraviolet radiation exposure of 457 workers in the Danish summer season. Presented as semi-annual standard erythemal dose (SED) on working days, respectively, at leisure, the results are for mainly outdoor workers 214.2 SED and 64.8 SED, equal-parts-outdoor-and-indoor workers 131.4 SED and 64.8 SED, indoor workers 55.8 SED and 57.6 SED. The daily SED by month is significantly different ($\alpha = 0.05$) between mainly outdoor, equal-parts-outdoor-and-indoor and indoor workers and across professional groups; some of which are exposed at very high levels that is roofers 361.8 SED. These findings substantiate that exposure to solar ultraviolet radiation is indeed an occupational health and safety problem in Denmark.

INTRODUCTION

Solar ultraviolet radiation (UVR) is rated as a group 1 carcinogen by the International Agency for Research on Cancer (IARC) and is a potential occupational health and safety problem (1). Lifelong cumulated exposure to solar UVR is the main etiological factor for squamous cell carcinoma (SCC) and actinic keratosis (AK), to some extend basal cell carcinoma (BCC) and may even affect the development of malignant melanoma (MM), as suggested by recent evidence (2,3).

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The intensity of solar UVR is particular high around noon where a large proportion of outdoor work is carried out with the consequent risk of developing work-related skin cancer (4). In Denmark, knowledge of solar UVR exposure at work and recognition of work-related skin cancer as a potential occupational health and safety threat are limited (2,5).

According to a registry study by the Danish Cancer Society, outdoor workers with more than 10 years of outdoor work in Denmark have a reduced the risk of skin cancer compared to the general population (6). This implies that Danish outdoor workers are exposed to cumulative doses of solar UVR that are lower than that of the general population, which is contra-intuitive.

Measurements of solar UVR exposure among Danish outdoor workers are sparse, and international and Danish experts in dermatology and occupational medicine (2,4,7) call for further exposure studies. For this purpose, personal UV-B dosimeters can be used to measure solar UVR exposure objectively, as proven feasible from a technical and practical viewpoint in a preceding study (8).

In Denmark, work-related exposure to solar UVR has only been measured among gardeners (9) and based mainly on those data, the solar UVR exposure of Danish outdoor workers in general is estimated at 224 standard erythemal dose (SED) per year (2). For reference, one SED equals an erythemal exposure of 100 J m^{-2} (8).

By comparison, detailed measurements of work-related solar UVR exposure in Germany show considerable variation among professional groups and has led to skin cancer being recognized as the third most common occupational disease in Germany (10–12). However, because of differences in latitude and working conditions, the German results may not be transferable to Danish conditions.

More than 150 000 Danes were diagnosed with nonmelanoma skin cancers (NMSC) in 2014, while as few as ninety cases of NMSC were reported to the Danish National Board of Industrial injuries of which only 28 were recognized as work related in 2015 (13–15). Detailed measurements of Danish outdoor workers exposure to solar UVR may help raise awareness on skin cancer as a potential occupational health and safety problem, as has been the case in Germany.

Threshold limit values (TLVs) for solar UVR exposure in the working environment are to some extent arbitrary (16). However, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) proposes the following TLV for occupational exposure: 1.0-1.3 SED per 8-h period to minimize long-term risk of skin cancer and photoaging (17) and below two SED, without prior UVR-induced skin adaption, and below five SED, with prior UVR-induced skin adaption, to prevent sunburn in Caucasians (18), based on the American Conference of Governmental Industrial Hygienists (ACGIH) action spectrum that considers both skin and eyes effect. For sunbed use, the International Electrotechnical Commission (IEC) (16) recommends a maximum annual UVR TLV of 150 SED. A firm TLV for solar UVR exposure in the working environment may serve as an effective tool in preventing work-related skin cancer.

To date, Danish sun protection campaigns have failed to stop the increase in skin cancer incidence by mainly targeting leisure time exposure. NMSC is the most prevalent form of cancer in Denmark; age-adjusted incidence rate is for basal cell carcinoma (BCC) almost one per thousand person-years and for squamous cell carcinoma (SCC) slightly more than one per ten thousand years (2,19,20). Despite increasing evidence of work-related solar UVR exposure as a substantial cause of skin cancer, in particular in low-latitude countries, efforts to promote protective sun safety measures among the estimated 400 000 Danish outdoor workers at risk are still not a priority (2,4,5,21–24).

Aim

To provide objective measurements of solar UVR exposure and compare levels of solar UVR exposure between groups of mainly outdoor workers, workers with equal-parts-outdoor-and-indoor-work and indoor workers at work and at leisure.

MATERIALS AND METHODS

Study design. Observational cross-sectional study of exposure to solar UVR at work and at leisure among Danish workers with varying degrees of outdoor and indoor work, based on objective measurements with portable UV-B dosimeters.

Setting. Nationwide study recruitment was carried out between April 2016 and May 2017. A number of Danish unions, municipalities and company health and safety organizations (named in the Acknowledgements section) supported the recruitment process by facilitating contact to their members and employees. Nationwide data collection was carried out between May and September 2016 and in April and May 2017.

Recruitment. A recruitment flyer was designed to advertise the study including provide workers with information about the purpose and requirements of the study and how to contact the principal investigator by phone or e-mail. The flyer was widely disseminated via hundreds of company- and personal emails and several professional journals, notice boards and at meetings. Thus, the total number of invited workers is estimated to be several thousands. Five hundred and thirty-one workers, from more than 50 different worksites, responded to the invitation by contacting the principal investigator and providing their personal e-mail address. A combination of a seven-item questionnaire sent via e-mail and contact by telephone was used to screen the respondents according to the following inclusion and exclusion criteria:

- Inclusion criteria: position as trainee or permanent construction worker, roofer, paver, gardener, road worker, bricklayer, carpenter, unskilled laborer, farmer, sailor, postal worker or similar professions involving mainly outdoor or equal-parts-outdoor-and-indoor work or machinist, porter or similar professions with mainly indoor work and an expected level of education matching that of the mainly outdoor workers.
- Exclusion criteria: insufficient Danish language skills, retirement or sick leave.

Written and spoken study information was given to eligible workers prior to getting their written consent as participants. Figure 1 provides details about the recruitment process and inclusions and exclusions as the study progressed.

Study questionnaire. The worker status of the participants in terms of outdoor and indoor work was obtained by a single question, where participants stated whether their work was mainly outdoor, equal-parts-outdoor-and-indoor or mainly indoor (indoor). The professional group association of the participants was obtained by questions regarding education, employment and current profession. The study questionnaire also requested information on demographic and health characteristics, occupational history, attitude toward occupational skin cancer risk and use of sun protection and a short form health survey (SF-12) (K. Grandahl unpublished data).

Study population. Construction workers (unskilled, technicians, concrete and sewer construction), gardeners, roofers, postal workers, road workers, dockworkers, carpenters and masons represented the mainly outdoor workers. Carpenters, dockworkers and surveyors represented the workers with equal-parts-outdoor-and-indoor-work. Porters, administration workers, crane technicians and blacksmiths represented the indoor workers.

Dosimetry. One hundred and two wristwatch-sized personal UV-B dosimeters, developed by Scienterra Limited (NZ), with an aluminum gallium nitride (AlGaN) photodiode detector that has a very low sensitivity to radiation with wavelengths above approximately 320 nm (insensitive to light) were used to measure the participants' UVR exposure. At preset intervals, the photodiode signal is sampled and converted by an analog-to-digital converter into a 10-bit digital value or "count" between 0 and 1023 and stored with a timestamp in FLASH memory.

The dosimeters were calibrated from sunrise to well after solar noon on a cloudless spring day by being placed in horizontally and in close proximity of the reference instruments, a Brewer MkIII Spectrophotometer and a Yankee Environmental Systems UVB-1 radiometer on the roof of the Danish Meteorological Institute (DMI) in Copenhagen (ref. 8 and Appendix S1).

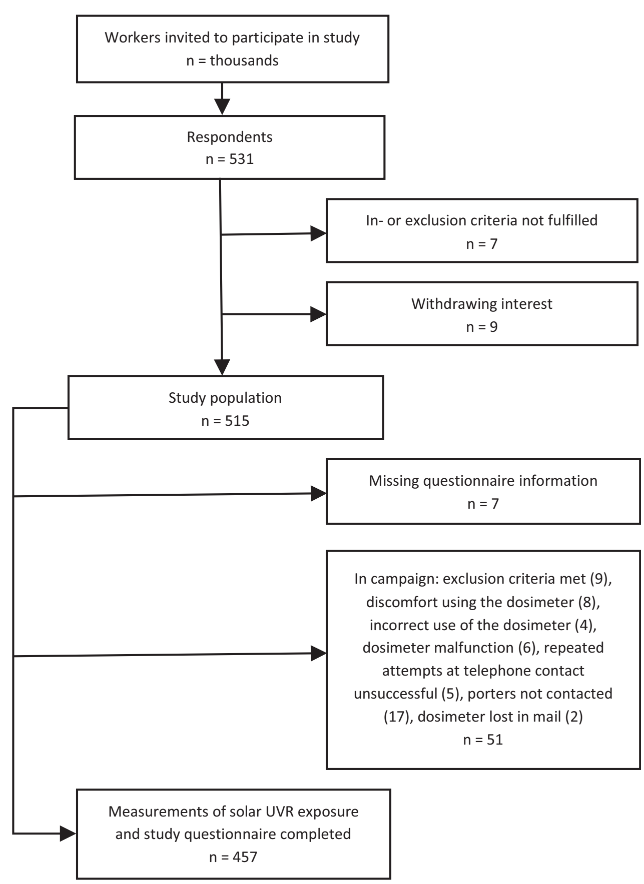

Figure 1. Recruitment flowchart.

The Brewer instrument, working as a spectroradiometer, is calibrated by several 1-kW DXW standard lamps of spectral irradiance with traceability to National Institute of Science and Technology (NIST) (25) either through GH Instruments in Florida or Research Institutes of Sweden in Borås, Sweden, depending on the lamp used. The instrument's angular responsivity has been measured, and its measurements during calibration have therefore been "cosine corrected," that is, corrected for nonideal angular responsivity. Measurement from the Brewer instrument has been compared to measurements by Qasume, a European standard instrument for UV-measurements (26), with excellent results. The Brewer instrument has been used to calibrate the UVB-1 radiometer along the lines depicted in the Appendix S1. Generally, the Brewer instrument takes measurements every 15–20 min, but the UVB-1 takes measurements every minute. As the angular responsivity of the UVB-1 radiometer is excellent, the measurements from the two instruments agree to within 2%. This is also to be expected as the Brewer instrument has calibrated the UVB-1. At very low solar elevation, the instrument's measurements sometimes differ by more mostly because of higher uncertainties in the angular responsivity. For the calibration of the dosimeters, we chose to utilize the 1-min measurements of the UVB-1 radiometer to get a fixed time interval. A radiative transfer program (SMARTS) was also used to supply supporting data during calibration for quality control. For each dosimeter, a set of three calibration coefficients was determined. The first two were determined by relating the reference instruments CIE-weighted irradiance (x) to the dosimeter's counts (y) at 1-min intervals and fitting a second-order polynomial (forced through 0,0) to the set of points (x,y) obtained. Up to 400 counts, approximately, the maximum signal encountered during calibration, this was indeed a very good fit for all dosimeters, determining the first two calibration coefficients. At higher counts, however, the irradiance, or dose rate, may be highly over- or underestimated depending upon the sign of the coefficient to the counts squared. We therefore chose to limit the polynomial fit to count values smaller than 400 counts and use a "linear" coefficient for higher counts, the linear coefficient, the third calibration coefficient, being determined from the average counts in a 1-h interval during noon.

Following calibration, the dosimeters were set to measure every 10 s from 7 AM until 7 PM local time and dispatched in batches of approximately 45 at 2-week intervals allowing for twelve measurement cycles between May–September 2016 and April–May 2017 (8).

Upon receipt of the dosimeter, each participant was instructed to wear the dosimeter daily between 7 AM and 7 PM on the dorsal side of the wrist or lower arm for a continuous period of ten workdays and four leisure days and each day report the use of the dosimeter by daily text messaging (8). After use and upon return, the dosimeter's timestamped counts were read in a text data format and then used in the following data analysis.

Further technical details for the dosimeters including the spectral responsivity in relation to the CIE erythemal action spectrum (27) and the angular responsivity in relation to the ideal cosine and how it may affect the calibration of the dosimeters and the results of this study can be found in the Appendix S1.

Data analysis. The text data-formatted timestamped counts were converted to erythemally weighted irradiance, or standard erythema dose rate (SED/h) using a set of three calibration coefficients specific for each dosimeter.

A computer program was developed to process this conversion of timestamped counts into SED: calculating date-specific solar UVR exposures at hourly intervals and as daily exposures for each participant.

Daily measurements with more than 360 data points (1 h) missing were excluded in the final analysis. In total, measurements from 18 participants, comprising 22 workdays and 7 days off, were excluded on this basis.

Measurements of a daily solar UVR exposure of more than 10 SED were, first, checked for noncompliance in the form of prolonged (more than 30 min) data point patterns without fluctuations, indicating a stationary dosimeter position incompatible with use of the dosimeter on the wrist or lower arm and, second, checked against data from the DMI. A total of 71 days showing an exposure of more than 10 SED were identified and checked. Of these, 9 days off and eight workdays from eleven mainly outdoor workers and 3 days off from two equal-parts-outdoor-and-indoor worker were considered noncompliance and excluded in the final analysis. When we compared the remaining 51 days to the corresponding solar UVR measurements made by DMI, no apparent discrepancies were found.

Statistical analysis. The solar UVR exposure on working days and at leisure of each worker was calculated as monthly mean. Group results are presented as a median value and an interquartile range. Histograms were used to check for normal distributions and Levene's test for equality of variance to check for homogeneity of variance between groups. Nonparametric statistics was used, as most of the data were not normally distributed. Specifically, the Kruskal–Wallis H-test, as standard and posthoc pairwise comparison with Bonferroni correction for multiple tests and Mann–Whitney U-test were used to compare unpaired continuous data between groups (28). Statistical significance was determined using $\alpha = 0.05$. IBM SPSS version 24 (SPSS Inc., Chicago, IL) was used for data analysis.

The Region Zealand Ethical Scientific Committee and Data Monitoring Authority approved the study. File numbers: SJ-509 and REG-130-2015. The study was conducted in accordance with the principles of the Declaration of Helsinki.

RESULTS

Overview of collected data

Measurements of solar UVR exposure were completed by 457 workers. Hereof, 454 completed measurements on working days and 445 completed measurements at leisure. The total number of days measured is for mainly outdoor workers 3659 work days and 1687 leisure days, for workers with equal-parts-outdoor-and-indoor work 583 work days and 248 leisure days, for indoor workers 410 work days and 165 leisure days. The number of days measured, as median and interquartile range, was for mainly outdoor workers, 10 (3) on working days and four (2) at leisure, for workers with equal-parts-outdoor-and-indoor work, it was 10 (3) on working days and four (2) at leisure, and for indoor workers, it was 10 (1) on working days and four (1) at leisure.

Exposure to solar UVR on working days by mainly outdoor, equal-parts-outdoor-and-indoor and indoor groups

Table 1 shows solar UVR exposure on working days as daily median and interquartile range (in SED) by month and cumulated semi-annual exposure (in SED) for groups of 357 mainly outdoor workers, 58 workers with equal-parts-outdoor-and-indoor-work and 39 indoor workers. The difference in cumulated semi-annual exposure on working days between mainly outdoor workers and indoor workers is 158.4 SED or a factor 3.8, between mainly outdoor workers and workers with equal-parts-outdoor-and-indoor-work 93.6 SED or a factor 1.8 and between mainly outdoor workers and the total sample population (all workers) 84.0 SED or a factor 1.6.

Exposure to solar UVR exposure on working days by profession

Table 2 shows solar UVR exposure on working days as daily median and interquartile range (in SED) by month and cumulated semi-annual exposure (in SED) for 17 different professions. The cumulative UVR exposure (in SED) of roofers exceeds that of all other professions and that of the outdoor workers category in Table 1. The latter also applies to concrete workers, road workers, concrete technicians, sewer construction workers, scaffolders, renovation workers and surveyors. The cumulated semi-annual exposure on working days of various indoor workers is lowest and 77.6 SED or a factor 2.3 lower than that of carpenters, the profession with

Table 1. Solar ultraviolet radiation exposure on working days as daily median and interquartile range (in SED) by month and cumulated semi-annual exposure (in SED), with each month set at 18 workdays, by workers status as mainly-outdoor, equal-parts-outdoor-and-indoor and indoor.

		Month						
Worker status	*N*	April*,‡	May*,‡	June*,†,‡	July*,‡	August*,†,‡	September*,‡	Cumulated
Mainly outdoor	357	1.6 (1.9)	2.4 (2.1)	2.2 (1.5)	1.8 (1.8)	2.3 (1.8)	1.6 (1.7)	214.2
Equal-parts-outdoor-and-indoor	58	0.7 (1.5)	1.3 (1.8)	1.0 (1.3)	1.2 (1.6)	1.3 (1.8)	1.2 (1.1)	120.6
Indoor	39	0.2 (0.5)	0.5 (0.8)	0.6 (–)	0.5 (0.8)	0.7 (0.6)	0.6 (0.7)	55.8

SED, standard erythemal dose. *All measures significantly different between mainly outdoor and indoor groups. †All measures significantly different between mainly outdoor and equal-parts-outdoor-and-indoor groups. ‡All measures significantly different between mainly outdoor and equal-parts-outdoor-and-indoor and indoor as one group. (–) less than four workers in-group.

Table 2. Solar UVR exposure on working days as daily median and interquartile range (in SED) by month and cumulated semi-annual exposure (in SED), with each month set at 18 workdays), by profession.

		Month						
Profession	*N*	April*	May*	June*	July*	August*	September	Cumulated
Roofer	36	2.7 (2.7)	2.8 (2.9)	4.7 (8.9)	2.4 (–)	4.6 (2.5)	2.9 (1.3)	361.8
Concrete worker	17	2.1 (–)	4.2 (5.6)	3.4 (–)	2.1 (1.6)	2.6 (3.4)	1.2 (2.9)	280.8
Road worker	29	2.0 (–)	2.4 (–)	3.3 (1.7)	3.5 (4.3)	2.6 (1.2)	1.5 (1.2)	275.4
Concrete technician	17	2.5 (6.8)	4.5 (4.4)	2.2†	2.3 (–)	2.5 (2.3)	1.2 (4.1)	273.6
Sewer construction worker	7	1.6†	2.2 (–)	2.2†	4.8 (–)	1.8 (–)	2.6 (–)	273.6
Scaffolding worker	5	2.1 (–)	2.1 (–)	2.2†	3.7 (–)	1.8 (–)	1.6 (–)	243.0
Renovation worker	8	1.6†	2.2 (–)	2.4 (–)	3.5 (–)	1.4 (–)	1.6†	228.6
Surveyor	5	0.7†	1.4†	2.0 (–)	3.6 (–)	2.7 (2.2)	1.8 (–)	219.6
Gardener	79	1.4 (1.1)	2.2 (2.1)	2.3 (1.3)	1.8 (1.8)	2.0 (2.1)	2.0 (2.4)	210.6
Postal worker	33	0.5 (0.3)	2.4†	2.7 (–)	1.9 (1.9)	1.8 (1.8)	2.0 (2.4)	203.4
Mason	12	1.6 (2.2)	1.6 (2.1)	2.2†	1.3 (–)	1.8 (5.0)	2.0 (–)	190.8
Machine operator/driver	15	0.4 (–)	2.4 (–)	2.2 (–)	3.1 (–)	1.2 (4.4)	0.9 (–)	183.6
Various other outdoor	41	1.8 (–)	2.0 (2.4)	1.7 (1.7)	1.8 (1.4)	1.0 (1.6)	1.4 (1.1)	174.6
Unskilled laborer	43	0.3 (–)	2.4 (1.8)	1.3 (2.0)	1.5 (2.2)	2.3 (1.8)	1.6 (1.2)	169.2
Dockworker	30	1.9 (–)	1.5 (0.8)	1.8 (1.1)	0.9 (1.3)	1.1 (–)	0.9 (–)	145.8
Carpenter	38	0.7 (–)	1.1 (1.1)	1.8 (2.1)	1.3 (1.9)	2.0 (1.2)	0.7 (–)	138.6
Various indoor	39	0.3 (0.4)	0.5 (0.8)	0.6 (0.7)	0.8 (0.8)	0.6 (0.5)	0.6 (0.5)	61.2

SED, standard erythemal dose; UVR, ultraviolet radiation. *All measures significantly different across professions. In professions with missing solar UVR exposure data for more than 2 months, workers are categorized as various other outdoor or various indoor workers based on their worker status. Professions where one or two solar UVR exposures are missing are supplemented with the corresponding values from Table 1 as proxy based on predominant worker status and indicated with an †. (–) less than four workers in-group.

the second lowest cumulated semi-annual exposure on working days.

Note: the categories indoor (Table 1) and various indoor (Table 2) have slightly different composition in that two teachers, a cleaning assistant, an indoor industry worker, an administrative worker and a crane technician are categorized as various indoor in Table 2 and as workers with equal-parts-outdoor-and-indoor-work in Table 1. Conversely, six workers categorized as indoor workers in Table 1 are categorized as a concrete worker, a dockworker, a machine operator/driver, an unskilled laborer and two concrete technicians in Table 2.

Exposure to solar UVR exposure at leisure by mainly outdoor, equal-parts-outdoor-and-indoor and indoor groups

Table 3 shows solar UVR exposure at leisure in Denmark as daily median and interquartile range SED by month and cumulated semi-annual exposure (in SED) for groups of 352 Danish mainly outdoor workers, 55 workers with equal-parts-outdoor-and-indoor-work and 38 indoor workers. The cumulated semi-annual exposure at leisure of indoor workers is 14.4 SED or a factor 1.25 lower than that of worker with equal-parts-outdoor-and-indoor work and 7.2 SED or a factor 1.1 lower than that of workers with mainly outdoor work.

Temporal distribution of exposure to solar UVR on working days by mainly outdoor, equal-parts-outdoor-and-indoor and indoor groups

Figure 2 shows temporal differences in median exposure to solar UVR (in SED) for mainly outdoor, equal-parts-outdoor-and-indoor and indoor workers on working days. The median exposure to solar UVR is more or less evenly distributed at hourly intervals from 10 AM until 3 PM for mainly outdoor workers and roughly the same for all three groups after normal working hours from 4 PM until 7 PM.

DISCUSSION

This study shows that Danish mainly outdoor workers are exposed to significantly higher levels of solar UVR than indoor workers, workers with equal-parts-outdoor-and-indoor-work and all workers on working days in the summer season. In contrast, the solar UVR exposure levels are not significantly

Table 3. Solar UVR exposure at leisure as daily median and interquartile range (in SED) by month and cumulated semi-annual exposure (in SED), with each month set at 12 days off, by worker status as mainly outdoor, equal-parts-outdoor-and-indoor and indoor.

		Month						
Worker status	*N*	April*	May*	June*	July*	August*	September*	Cumulated
Mainly outdoor	352	0.5 (1.0)	1.0 (1.3)	1.3 (1.6)	0.9 (1.3)	0.8 (0.9)	0.9 (1.2)	64.8
Equal-parts-outdoor-and-indoor	55	0.4 (1.4)	0.7 (1.3)	1.6 (1.5)	0.8 (1.2)	0.9 (1.9)	1.6 (2.2)	72.0
Indoor	38	0.4 (0.6)	1.2 (0.9)	1.3 (–)	0.8 (0.7)	0.5 (0.7)	0.6 (1.2)	57.6

*All measures none significantly different across workers status groups. (–) less than four workers in-group. SED, standard erythemal dose; UVR, ultraviolet radiation.

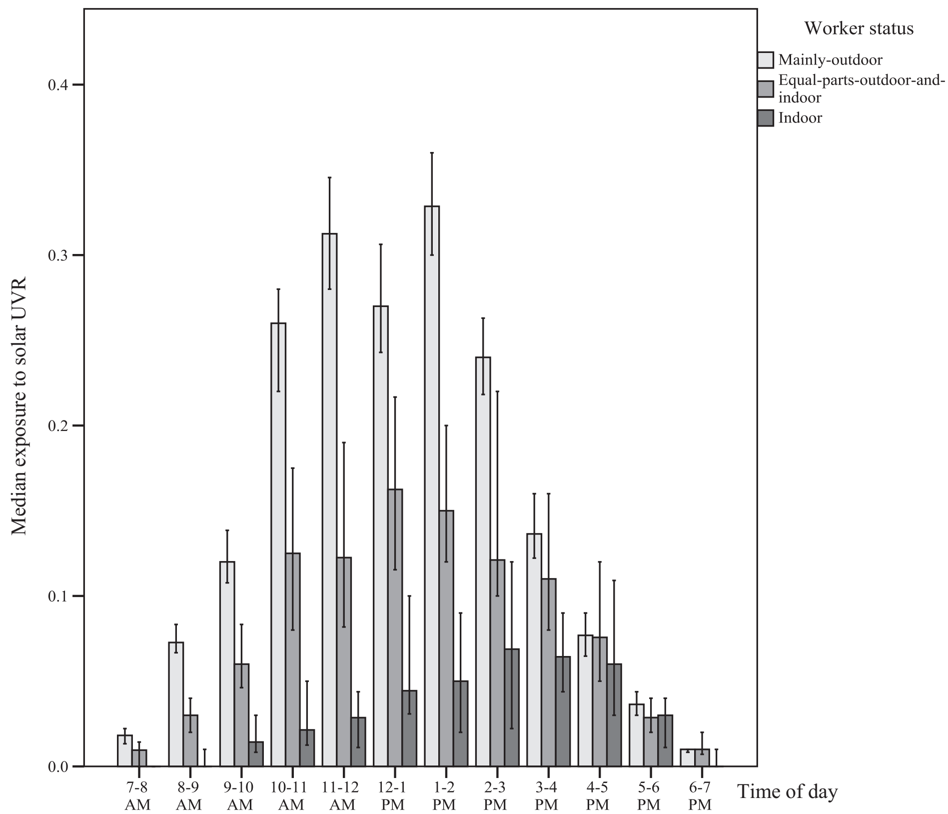

Figure 2. Median exposure to solar ultraviolet radiation (UVR) (in standard erythemal dose) on working days, at hour intervals, for workers with different outdoor worktime with 95% CI.

different between these groups at leisure and after working hours.

The cumulated semi-annual exposure to solar UVR is particularly high for Danish roofers on working days and as much as a factor 1.7 higher than that of mainly outdoor workers (in Table 1). Bearing in mind that their work is mostly carried out on top of buildings with relatively little shade, this is not surprising. The cumulated semi-annual exposure to solar UVR is also relatively high for building trade workers such as concrete workers, road workers, concrete technicians, sewer construction workers, scaffolders, renovation workers and surveyors when compared to mainly outdoor workers (in Table 1).

Practically, all professions have a daily median solar UVR exposure that is well above the ICNIRP TLV for UVR exposure of 1.0–1.3 SED per 8-hour period proposed to minimize long-term risk of skin cancer and photoaging throughout the summer season (17). Half of the professions exceed the ICNIRP TLV for UVR exposure of two SED without prior UVR-induced skin adaption to prevent sunburn in Caucasians in the spring months of April and May (18). In addition, all professions (apart from indoor workers, dockworkers and carpenters) fail to comply with the IEC maximum annual UVR TLV of 150 SED for sunbed use (16).

The solar UVR exposure of the mainly outdoor workers (Table 1) and most outdoor professions (Table 2) in this study is noticeably higher than shown in previous Danish studies. This applies to both the daily median solar UVR exposure of 1.6 SED at work measured on the wrist of Danish Gardeners in 2005 and the combined solar UVR exposure at work and leisure in Denmark of outdoor worker set at 224 SED per year by a Danish expert group in 2013 (2,9).

Compared to the results of the previous study of Danish gardeners (9), our study shows slightly lower exposures at leisure. In the previous study, measurements were made with participants both in Denmark and on sun holidays, which may explain the difference between the two studies. On sun holidays, the average solar UVR exposure is measured to be 57 SED per week (29). No other major methodological differences exist between this study and the previous Danish study.

By comparing measurements of solar UVR exposure between Danish and German outdoor workers, significant differences that indicate different behaviors and working conditions in some professions seem to be the case between countries, regardless of major methodological differences (10,11 and B. Strehl, personal communication).

The relatively large interquartile ranges presented in this study indicate a substantial variation in the daily median solar UVR exposure of most professions. This reflects sizable work-related behavioral differences within professions and illustrates an additional need for solar UVR exposure data that include information on specific work-related tasks within professions.

The considerable variation in solar UVR exposure shown in this study within professions also emphasizes the risk of exposure misclassification in registry-based studies—if the between-person variation is substantially higher than within-person variation in the various jobs.

The results in this study generalize exposure to solar UVR among professional groups. However, it is important to remember that individual exposure to solar UVR at work largely depends on a number of environmental factors such as work tasks, time and duration of work, posture, season as well as the reflection or shade from the surrounding local environment (30).

Like it is the case for use of sun protection (K. Grandahl, unpublished), the solar UVR exposure of Danish workers in this study cannot explain why Danish outdoor workers in general reportedly have a low risk of skin cancer compared to the general population (6).

Skin adaption from regular exposure to solar UVR at work may explain why outdoor workers seem to be somewhat protected against UVR. In particular, thickening of the stratum corneum part of the skin, induced by regular exposure to solar UVR, may lead to increased protection against UVR by a factor of five or even higher and is probably more important than skin pigmentation in providing endogenous photo protection in Caucasians. In contrast, a more sporadic exposure to solar UVR at leisure cannot produce enough thickness to protect the basal layer (30).

Finally, yet importantly, this study clearly illustrates a need for prevention of solar UVR exposure at Danish workplaces and enables a novel distinction between professions that can be used to identify and target risk professions in a preventive context. Interestingly, the median solar UVR exposure dose of outdoor workers on working days is fairly even at hourly intervals between 10 AM and 15 PM, the time interval in which the major part of the median daily solar UVR exposure occurs. Consequently, the need to prevent exposure to harmful levels of solar UVR at work extends well beyond the time around noon, that is, avoiding the sun only during the lunch break is inadequate.

Strengths and limitations

Using a well-documented method that is both practically and technically feasible to perform personal solar UVR exposure dosimetry on working days and at leisure among more than four hundred workers representing many different professions nationwide is a major strength of this study and unprecedented in Denmark (8).

Risk of selection bias from worker self-selection and prescreening is markedly reduced by our choice to measure the solar UVR exposure for a large number of outdoor workers over shorter periods, as opposed to fewer over longer periods.

A clear distinction between time at work and before or after working hours on working days is somewhat hampered by the fact that we only know that the work took place, in whole or in part, sometime between 7 AM and 7 PM. It is, however, reasonable to assume that daytime work is predominant in our study population, as is the case for Danish workers in general (31).

The relatively small number of sewer construction workers, renovation workers, scaffolding workers and surveyors in this study causes the median solar UVR exposure by month to be less generalizable for these professions and should be expanded by further measurements. The same applies to unskilled laborers due to the abnormally low median solar UVR exposure dose from only one participant in April.

This study has neither data on solar UVR exposure outside the Danish summer season nor on exposure of participants/workers on sun holidays. However, outside the Danish summer season, solar UVR is quite low and contributes very little to the annual solar UVR exposure (32).

By excluding 20 noncompliance measurements showing exposures above 10 SED and by calculating cumulative semi-annual exposure to solar UVR based on medians rather than means, a more conservative estimate is presented.

Finally, the highly accommodating and willing approach to this study by the health and safety organizations of several Danish contractors is also considered a strength. Certainly, it provides a good common starting point for implementing an effective use of sun protection at Danish workplaces.

CONCLUSION

The solar UVR exposure levels presented in this study are higher than previously shown for Danish outdoor workers and significantly different across professional groups on working days (2). These findings indicate a greater risk of work-related skin cancer among certain professional groups than previously assumed.

That certain professional groups are exposed to solar UVR at very high levels and hardly any have exposure that are below the proposed TLV of daily and annual UVR exposure in the summer season (17,18) furthermore emphasizes the importance of sun safety in Danish workplaces. This applies especially during the working hours between 10 AM until 3 PM where most of the solar UVR exposure occur, as demonstrated in this study.

Exposure to solar UVR on working days is significantly higher for mainly outdoor workers compared to workers with less outdoor work. No such differences were found for solar UVR exposure at leisure. These findings indicate that risk of skin cancer may be relatively high for workers with mainly outdoor work and substantiates the need for further studies of skin cancer risk in outdoor workers, based on more detailed exposure data.

The fact that exposure to solar UVR on working days also appears to vary a great deal within professional groups implies environmental dependence in that exposures to solar UVR depends on specific work task and needs to be investigated by further measurements of solar UVR exposure at work.

Acknowledgements—We wish to thank our recruitment partner unions: 3F, Dansk Byggeri and Asfaltindustrien; municipalities: Copenhagen, Middelfart and Bornholm; company health and safety organizations: NCC, MT Højgaard, CG Jensen, Aarsleff, JORTON (construction), MALMOS and Grøn Vækst (landscaping), Copenhagen Malmö Port (dockwork), Dansk Retursystem (indoor industry), Holbæk and Roskilde Regional Hospitals, the Danish National Postal Service and The Preventive Service Bus (construction).

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Technical details for the dosimeters; including the spectral responsivity in relation to the CIE Erythemal action spectrum and the angular responsitivity in relation to the ideal cosine and how it may affect the calibration of the dosimeters.

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