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Personal solar ultraviolet radiation dosimetry in an occupational setting across Europe

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Abstract (256 words)

Background

Work-related solar ultraviolet radiation (UVR) is an important factor in the pathogenesis of non-melanoma skin cancer (NMSC). The World Health Organization, through the International Agency for Research on Cancer (IARC), has classified solar UVR as a group 1 carcinogen since 2012. The main problems encountered so far in the study of occupationally induced skin cancer include the lack of accurate occupational UVR dosimetry as well as insufficient distinction between occupational and leisure UVR exposure and underreporting of NMSC.

Objectives

The aim of this study was to collect long-term individual UVR measurements in outdoor workers across European countries.

Methods

A prospective study was initiated through the European Academy of Dermatology and Venereology, Healthy Skin@Work Campaign, measuring UVR exposure doses at occupational settings of masons from five European countries. Measurements were performed for several consecutive months using the GENESIS-UV measurement system.

Results

The results identified alarming UVR exposure data. Average daily UVR doses ranged 148.40 - 680.48 J/m² in Romania, 342.4-640.8 J/m² in Italy, 165.5-466.2 J/m² in Croatia, 41.8-473.8 J/m² in Denmark, and 88.15-400.22 J/m² in Germany. Results showed an expected latitude dependence with increasing UVR yearly dosage from the north to the south of Europe.

Conclusions

This study shows that outdoor workers from EU countries included in this study are exposed to high levels of occupational solar UVR, vastly exceeding the occupational exposure limits for solar UVR exposure, considered to be 1-1.33 SED/day in the period from May to September.

This finding may serve as an evidence-based recommendation to authorities on implementing occupational skin cancer prevention strategies.

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Introduction

Work-related solar ultraviolet radiation (UVR) is an important factor in the pathogenesis of non-melanoma skin cancer (NMSC), including precancerous lesions such as actinic keratosis (AK) and invasive cutaneous carcinomas, i. e. cutaneous squamous cell carcinoma (cSCC) and basal cell carcinoma (BCC) [1]. The World Health Organization (WHO) through the International Agency for Research on Cancer (IARC) has raised the issue of solar UVR being a carcinogen to humans since 1992 and has classified solar UVR as a group 1 carcinogen since 2012 [2].

In the European Union, at least 14.5 million workers are exposed to solar UVR by spending 75% of their working time outdoors [3]. High-risk professions include construction workers, roofers, road workers, fishermen, farmers, dock workers etc. The risk of developing some form of NMSC is significant higher in occupationally exposed individuals compared to the general population [4]. Recent studies have shown that outdoor workers (OW) that are exposed to solar UVR at work have twice the risk of incident BCC and cSCC compared to non-outdoor workers with less total lifetime solar UVR exposure [5, 6]. Furthermore, special characteristics of BCC in OW were identified: lesions arise frequently on the “mask area” of the face and usually present a more aggressive histological subtype [7]. Occupational NMSC is characterized by long induction periods (years or even decades) and chronic actinic damage. The first signs of skin cancer may even appear after retirement following many years of cumulative occupational solar UVR exposure, becoming an important issue in our increasingly ageing population [8].

Costs related to treatment of NMSC can substantially be reduced by effective preventive public health strategies. Still, up to 90% of skin cancer related budget is invested in treatment and only 10% in prevention [9]. Healthy Skin@Work Campaign, raised by the European Academy of Dermatology and Venereology (EADV), is a prevention campaign whose aim it is to increase awareness of occupational skin diseases at national and international levels in Europe. Within this campaign, the sub-campaign Skin Cancer: Safe Work Under the Sun was started, focusing on outdoor workers and skin cancer risk related to their significant occupational solar UVR exposure. The goal of this sub-campaign was to improve the prevention of solar UVR exposure and reduce the occurrence of skin cancer in outdoor workers, by collecting relevant epidemiological data and advocating for EU legislation changes. Within the framework of the UN Sustainable Development Goals (SDG) 2030, the World Health Organization (WHO) and the International Labour Organization (ILO) are currently giving this topic a high priority, by developing a joint methodology to assess the global disease burden of work-related skin cancer by solar UVR exposure [10].

The main problems encountered so far in the study of occupationally induced skin cancer include the lack of accurate occupational UVR dosimetry as well as insufficient distinction between occupational and leisure UVR exposure and underreporting of NMSC [11,12]. The recently performed solar UVR dosimetry in Germany, by Wittlich et al. [13], has shown promising results in estimating the cumulative annual solar UVR exposure in OW. The aim of this study was to collect long-term measurements of individual solar UVR exposure in groups of OW across several European countries, in order to obtain a comprehensive database of solar UVR dosage, essential for further developments of the research in the field of occupationally induced skin cancers.

Material and methods

Data collection started in 2014/2015 in Germany through the GENESIS-UV (GENeration and Extraction System for Individual exposure) study [13] and was continued using the same methodology in 2017 in other European countries (Croatia, Denmark, Italy, and Romania) that agreed to participate in a prospective study within the project no. 18 of the European Academy of Dermatology and Venereology (EADV), named „Joint scientific implementation and evaluation of the Healthy Skin@Work Campaign”.

The studied profession was masons. The participants were selected as volunteers from the local building companies which agreed to cooperate. The participants received financial compensation. The main work-tasks performed by the masons (during measurements) included setup and clearing of construction site, earthwork, foundation and bottom plate construction, drainage and building lateral line construction, exterior and interior wall construction, ceiling, bearer and stairs construction and sealing and residual work. In Romania, 9 OW were included from a region near Bucharest (lat. 44°17'0"N, long. 25°32'0"E) and from Targu Mures (lat. 46°32'44"N, long. 24°33'45"E). The project was conducted from April until the end of October 2017. In Italy, 4 construction workers from Tuscany region, working as masons in various construction sites in the province of Siena (lat. 43.3° N, long. 11.3° E) have been measured from the beginning of May to the end of September 2017. Since it is usual to take longer annual leave in August in Italy, measurements were not performed during this month. In Croatia, data for 4 construction industry workers, working in the vicinity of Zagreb (lat. 45.8° N, long. 16.0° E), were collected in the period from June to October 2017. In Denmark (lat. 56° N), UVR measurements were carried out nationwide in 3 masons working in various construction sites between April and October. Data from Germany was from 2014 and 2015 for 16 masons working throughout the country in various construction sites for 7 consecutive months (April to October). Since large number of measurements was already collected in Germany during the 2014/2015 period, measurements were not repeated in 2017. However, the mean sunshine duration in Germany was monitored via the German Meteorological Service (Deutscher Wetterdienst, DWD) and this data showed that the weather in the years 2014/2015 lied within the 30-years average of the sunshine duration. Thus, due to the comparable weather conditions and the same methodology used, the German UV data was considered to be representative for other years as well and was included in this study. Nevertheless, the results for Germany are shown separately.

The occupational solar UVR exposure monitoring was performed with the GENESIS-UV methodology. GENESIS-UV is a system for decentralized measurements of individual UVR exposure mainly consisting of an electronic data logger dosimeter, a tablet PC for data storage and transmission, and accessory parts (Figure 1). The electronic dosimeters "X-2012-10" (Gigahertz, Turkenfeld, Germany) register the UVR irradiance in the UVA and UVB/C regions separately. Each worker was equipped with a dosimeter to be worn on the left upper arm

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during working hours. The left upper arm was chosen due to wearing comfort and compliance. The dosimeter was carried in an upper arm holder, which had been manufactured in cooperation with a medical supply store, and a positive feedback from workers was received. The participants were instructed to wear dosimeters over their clothes. UVR exposure was constantly registered from 7.00 a.m. to 5.00 p.m. for five days per week (before 7.00 a.m. and after 5.00 p.m. available UV dose was considered to be small) [13]. The workers were instructed not to take off the dosimeters during the working time and thus the measurements reflect total exposure at workplace, including exposure during lunch breaks. Once a week the dosimeters have to be connected to the tablet PC to transfer the data to the data server in Germany. For data analysis, data was rearranged to yield a daily average value per month. Therefore, each data point was analysed for means of plausibility. The dosimeter records a combination of accelerometer and magnetic field data along with the UV exposure data with a resolution of one second. The acceleration sensor shows periods of rest or movement very sensitively. Furthermore, the UV data pattern of a dosimeter differs between resting periods and periods of movement. Thus, the periods of rest, e.g. if a worker forgot to take his dosimeter or left it resting in the sun, could be precisely identified from both the absolute value of the acceleration vector and the data pattern of a dosimeter. After carefully examining these two types of measurements, daily episodes where the dosimeter was virtually resting were excluded from analysis. A daily value was then calculated by summarizing the single second values of UV dosage measurements.

Statistical analysis

A descriptive analysis of data was performed. Daily values of all test persons of a certain month within a country were used to calculate a daily average per month, as well as standard deviation, standard error, minimum and maximum values, and range of values recorded in each month.

In addition to descriptive analysis, yearly exposure values for each country were calculated. Assuming a certain number of monthly working days (April, June, September 20 days, and May, July, August, October 21 days, respectively), a monthly exposure value m_i for month i was calculated by multiplying mean exposure value for a given month by the corresponding number of working days. With the help of a seasonal factor (Table 1), the sum of the above-mentioned data was extrapolated to a value for the entire year using the following formula:

$$\frac{\sum_i m_i f_s^{(i)}}{\sum_i f_s^{(i)}}$$

Here $f_s^{(i)}$ denotes the seasonal factor for month i . Only mean values calculated from at least 8 valid measurements contributed to the yearly exposure estimation, i.e. for each country the summations in formula are indexed over the months for which $N > 7$ in Tables 2 and 3.

Exposure to solar UVR is presented in J/m^2 and standard erythemal dose (SED; 1 SED=100 J/m^2).

Results

Table 2 shows the detailed information on the UVR recorded doses for data collected in 2017 (Romania, Italy, Croatia, and Denmark). Data for Germany, collected in 2014/2015, is shown in Table 3. Table 4 shows the extrapolated yearly exposure and Figure 2 latitude dependency of UVR average daily exposures across countries.

In Romania, average daily UVR doses ranged from 148.40 J/m^2 in October to 680.48 J/m^2 in April. Extrapolating these results, a yearly sum of 633 SED was calculated.

In Italy, average daily UVR doses ranged from 342.4 J/m^2 in July to 640.8 J/m^2 in May. A yearly sum of 671 SED was calculated for Italy.

In Croatia, average daily UVR doses peaked in July (mean value of 466.2 J/m^2), while lowest values were recorded in October (mean value of 165.5 J/m^2). Mean daily UVR exposures ranged from 0.4 SED (OW4) to 5.1 SED (OW1), indicating a high between-worker variability. A yearly sum of 519 SED was calculated for Croatia.

In Denmark average daily UVR doses ranged from 41.8 J/m^2 in October (the Danish summer season ends in September) to 473.8 J/m^2 measured in July, representing a mean daily UV exposure ranging between 0.4 and 4.7 SED. Note that for personal reasons DOW2 wore the dosimeter attached to his hat (and not on the upper arm). A yearly sum of 463 SED was calculated for Denmark.

In Germany, average daily UVR doses ranged from 88.15 J/m^2 in October to 400.22 J/m^2 in May. A yearly sum of 504 SED was calculated for Germany.

Results showed expected latitude dependence with increasing UVR yearly dosage from north to the south of Europe (Table 3, Figure 2).

Discussion

In this study, solar UVR exposure data were collected in outdoor workers from several European geographical regions, showing hazardous levels of solar UVR exposure in clear violation of the international threshold dosages [10]. Solar UVR exposure monitoring was performed using personal dosimeters. It was considered that workers must not be impaired by wearing the dosimeter, as this would falsify their behavior. In a study in Germany it has been shown that the left upper arm resembled the chest position [14], and exposure of other body parts can be approximated by the correction factors [13]. The participants were instructed to wear the dosimeters over their clothes, thus measurements should represent the doses that would be received by the unprotected skin. The methodology allowed differentiation between periods of rest and movement, thus it was possible to detect periods when a worker, most likely, did not wear the dosimeter, and exclude these periods from the analysis.

The yearly occupational UVR exposure dose of 633 SED in Romania shown in this study is unexpectedly high. This is especially true when compared to a previous German study where the annual UVR exposure was estimated at 130 SED in the general population and an additional 170 SED in outdoor workers [15]. Data previously gathered in Romania showed daily UVR doses ranging from 1.8 SED (farm car driver) to 19.0 SED (agriculture worker) with maximum UVR doses recorded between 10:00 am to 4:00 pm [16]. In Denmark, the average annual UVR exposure was previously estimated to be 168 SED in the general population and 224 SED in outdoor workers, based on a previous dosimetry study from 2005. In contrast, a more recent dosimetry study from 2018 showed higher levels of semi-annual solar UVR exposure in Danish outdoor workers as well as a significant variation between several outdoor occupations [17]. Danish roofers were the highest exposed with average doses of 4.7 SED per day in times of maximum solar activity [17]. These measurements were performed during the Danish summer season, on the wrist, and only included UVB [17]. In two previous studies, the average daily UVR erythemal dose received by a construction worker from the Tuscany region ranged between 3.5 and 6.5 SED, exceeding approximately 3-6 times the international occupational exposure limits for daily solar UVR exposure of 1-1.33 SED [10, 18, 19]. Regarding Croatia, these are the first occupational solar UVR exposure data in OW, indicating daily doses between 3.6 and 4.7 SED during the months of June, July, and August in masons working near Zagreb. However,

as Croatia and Italy each include regions with substantially different climates (mountainous, continental, Mediterranean), occupational UVR dosimetry should be collected in different climate regions for a complete exposure map in these countries. A former study found that German construction workers were exposed to daily occupational UVR doses of 215 SED[14], which is less than half of the dose recently measured with GENESIS-UV. In this study, German masons are exposed to a maximum daily dose of 4 SED and a yearly dose of 504 SED as a clear indication of excess exposure. Also, the exposure limit value [10] is regularly exceeded by a factor 4 in all the observed workers. The results of this study confirm the expected latitude dependence of occupational solar UVR exposures (Table 3, Figure 2).

Considering construction workers in Denmark, Italy and Croatia, the results of the measurement campaign is influenced by the relatively small number of involved workers compared to the measurement campaigns performed in the other involved European countries. While one of the study strengths is a large number of continuous measurements per worker, relatively small number of workers in some countries (e.g. $N = 3$ in Denmark and $N = 4$ in Italy and Croatia) presents a study limitation, as well as a notable between-worker variability in some cases. Including more workers would improve the accuracy of the yearly exposure estimation for these countries. The comparison of the data on masons with data found in the literature is hampered by the fact that most of the studies do not discriminate between the various occupations and work tasks in the construction industry. According to the German data, masons are among the construction workers with the highest UVR exposure. Thus, insufficient differentiation of exposure to UVR in construction workers entails a risk of exposure misclassification.

Some statistical limitations should also be mentioned for this study. Standard errors were in this study calculated as in the case of independent observations. Since some degree of autocorrelation might be expected due to the similar meteorological conditions for observations close in time and perhaps similar working conditions for the measurements of the same worker, these standard errors might be underestimated.

Conclusions

This study shows that outdoor construction workers from EU countries included in this study are exposed to high levels of occupational solar UVR, vastly exceeding the occupational exposure limits for solar UVR exposure, considered to be 1-1.33 SED/day in the period from May to

September. This finding serves as an evidence-based recommendation to authorities on implementing occupational skin cancer prevention strategies. Future studies and interactions with policy makers will serve as indispensable steps in changing legislation and notification strategies in high-risk professions throughout Europe. Additionally, a comprehensive European database on occupational skin cancer may serve as foundation in future guidelines development.

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Table legends

Table 1 - Values of the seasonal factor f_s on the northern hemisphere

Table 2 - Daily erythemal UVR exposure [J/m²] measured for outdoor workers (masons) in 2017 in different European countries

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For each country and month, descriptive statistics for all valid measurement days obtained from all included workers is shown. N: number of valid measurement days per month for all workers from the same country; SD: standard deviation; SE: standard error.

Table 3 - Daily erythemal UVR exposure [J/m²] measured for outdoor workers (masons) in 2014/2015 in Germany

For each month, descriptive statistics for all valid measurement days obtained from all included workers is shown. N: number of valid measurement days per month for all included workers; SD: standard deviation; SE: standard error.

Table 4 - Yearly exposure of workers. The data were extrapolated from average values of the monthly exposure

* Latitude taken for Bonn, for the whole country ranges between 47-55

Figure legends.

Figure 1: GENESIS-UV (GENeration and Extraction System for Individual exposure) system for measuring individual UVR exposure. The measuring equipment consists mainly of an electronic data logger dosimeter, to be worn on the left upper arm, a tablet PC for data storage and transmission, and accessory parts.

Figure 2: Average daily exposure in standard erythemal dose (SED) units across countries. For each country and month, average daily exposure is obtained from all valid measurement days of all included workers. For each country, only months with at least 8 valid measurements are shown. Data was collected in 2014/2015 (Germany) and in 2017 (all other countries).

Table 1 - Values of the seasonal factor f_s on the northern hemisphere

Month	Seasonal factor f_s	
January	0.015	(1.5 %)
February	0.025	(2.5 %)
March	0.055	(5.5 %)
April	0.100	(10.0 %)
May	0.150	(15.0 %)
June	0.185	(18.5 %)
July	0.170	(17.0 %)
August	0.140	(14.0 %)
September	0.090	(9.0 %)
October	0.045	(4.5 %)
November	0.015	(1.5 %)
December	0.010	(1.0 %)

Table 2 - Daily erythemal UVR exposure [J/m²] measured for outdoor workers (masons) in 2017 in different European countries

Daily Values [J/m ²]							
Romania							
	April	May	June	July	August	September	October
N	8	159	116	96	106	111	127
Mean UVR	680.48	368.05	450.09	451.95	360.52	258.44	148.40
SD	258.79	283.84	284.87	267.52	287.19	165.92	141.88
SE	91.49	22.51	26.45	27.30	27.89	15.74	12,58
Min	457.79	2.38	1.55	9.45	17.67	1.24	0,27
Max	1161.94	1161.78	1323.68	1205.49	2108.28	918.21	617,25
Range	704.14	1159.39	1322.12	1196.03	2090.61	916.97	616,98
Italy							
N	0	20	27	6	-	3	0
Mean UVR	-	640.83	451.08	342.38	-	572.46	-
SD	-	426.29	271.44	273.92	-	204.56	-
SE	-	95.32	52.24	111.83	-	118.10	-
Min	-	120.51	7.80	55.96	-	344.40	-
Max	-	1556.78	998.65	837.19	-	739.77	-
Range	-	1436.26	990.84	781.22	-	395.37	-
Croatia							
N	0	0	39	48	49	34	31
Mean UVR	-	-	398.60	466.21	358.77	195.58	165.53
SD	-	-	308.52	367.06	333.02	217.36	147.94
SE	-	-	49.40	52.98	47.58	37.27	26.57
Min	-	-	16.42	6.65	8.25	2.11	3.27
Max	-	-	1201.05	1132.23	1038.02	757.54	537.86

Range	-	-	1184.63	1125.58	1029.77	755.42	534.58
Denmark							
N	8	36	23	2	24	11	9
Mean UVR	207.97	393.38	473.70	715.76	285.93	203.96	41.76
SD	105.65	256.53	293.15	129.26	203.04	102.80	37.49
SE	37.35	42.76	61.13	91.40	41.45	30.99	12.50
Min	5.78	33.33	21.94	624.36	11.43	81.14	4.57
Max	324.32	914.68	961.52	807.17	756.16	381.93	128.17
Range	318.54	881.34	939.57	182.80	744.72	300.78	123.60

For each country and month, descriptive statistics for all valid measurement days obtained from all included workers is shown. N: number of valid measurement days per month for all workers from the same country; SD: standard deviation; SE: standard error.

Table 3 - Daily erythemal UVR exposure [J/m²] measured for outdoor workers (masons) in 2014/2015 in Germany

Daily Values [J/m ²]							
Germany							
	April	May	June	July	August	September	October
N	97	126	150	177	97	135	119
Mean UVR	338.87	400.22	380.66	398.74	334.79	216,76	88,15
SD	231.10	241.20	320.14	371.95	261.55	164,65	88,93
SE	23.46	21.49	26.14	27.96	26.56	14,17	8,15
Min	0.14	12.29	0.31	1.29	0.70	2,59	0,50
Max	991.39	1343.19	1513.27	1628.20	1024.50	896,02	531,95
Range	991.25	1330.90	1512.96	1626.91	1023.81	893,43	531,45

For each month, descriptive statistics for all valid measurement days obtained from all included workers is shown. N: number of valid measurement days per month for all included workers; SD: standard deviation; SE: standard error.

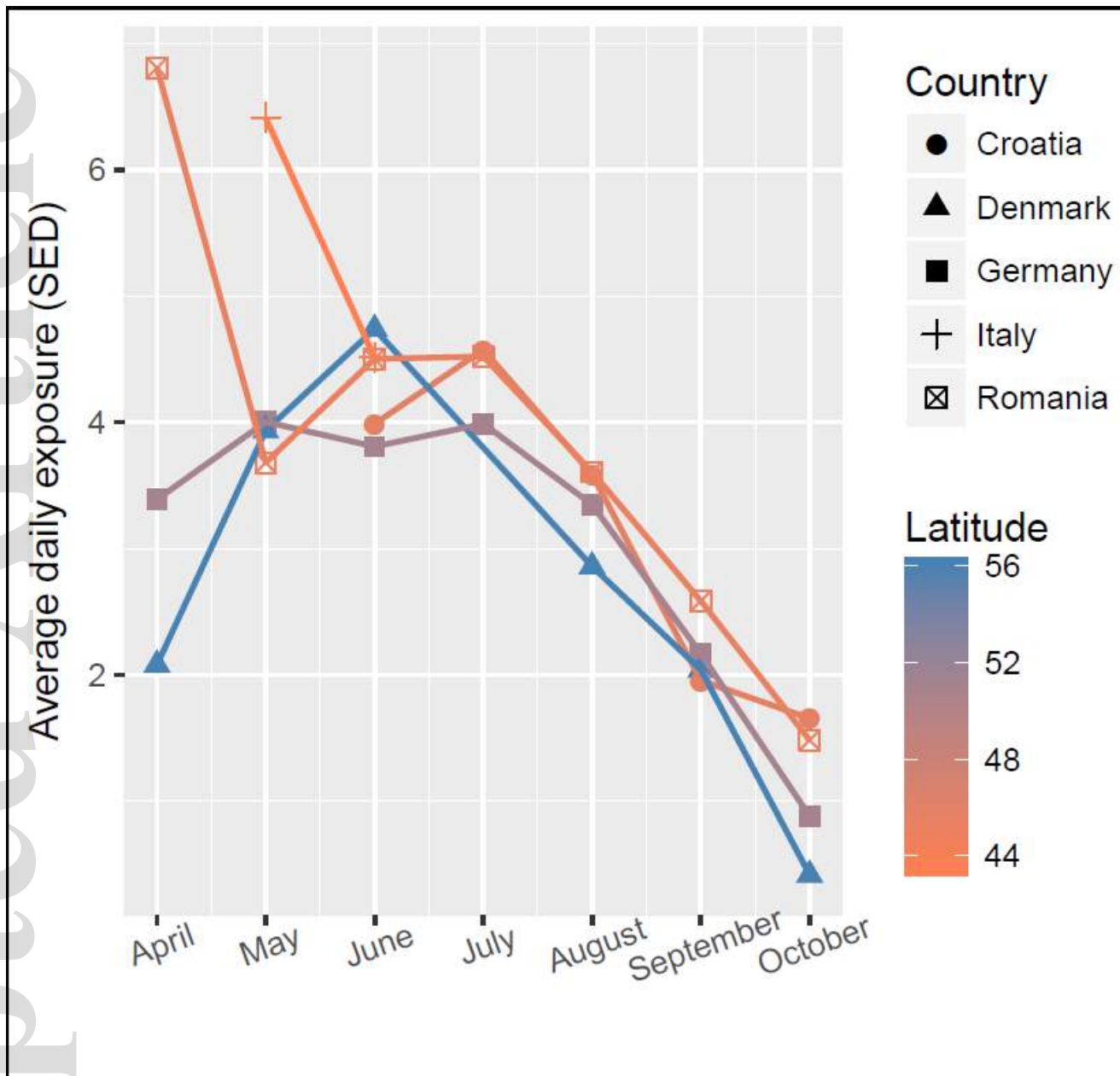
Table 4 - Yearly exposure of workers. The data were extrapolated from average values of the monthly exposure

Country	Latitude	Yearly exposure value (SED)
Denmark (2017)	56	463
Germany* (2014/2015)	51*	504
Croatia (2017)	45.8	519
Romania (2017)	45.25	633
Italy (2017)	34.3	671

* Latitude taken for Bonn, for the whole country ranges between 47-55



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