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Exposure to solar UV during outdoor construction work in Britain

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Abstract

Excessive exposure to ultra- violet (UV) radiation from the sun in summer can cause skin cancer and in Britain there are around 1,500 new cases of non-melanoma skin cancer (NMSC) each year, caused by exposure to solar UV at work. Little is known about the magnitude of UV exposure amongst outdoor construction workers in Britain, although this is one of the main groups at risk. The aim of this paper is to summarise measurements of erythema-weighted UVB radiation amongst construction workers in Scotland and the Southeast of England and interpret the data in terms of the risk of NMSC. The measurements were made as part of an intervention study using short mobile phone text messages to alter worker behaviour to either reduce UV exposure in summer or increase serum vitamin D in winter; the intervention is only briefly reported here. Data were collected from 67 workers from 9 worksites, of whom 41 provided measures of UV exposure for 758 working days. Daily exposure ranged from 0 to 13.47 SED, with the mean exposure for outdoor workers being 2.0 SED and the corresponding value for indoor workers being 0.7 SED. These data were obtained from a sensor located on the back of the workers hard hat; others have measured exposure on the wrist or upper arm and these locations probably, on average, have higher levels of UV exposure. It is likely that an outdoor construction worker in Britain could accumulate sufficient solar UV exposure over 30 to 40 years of work to more than double their risk of NMSC. We argue that employers in Britain should take a more proactive approach to manage sun safety and they should take responsibility for skin health surveillance for their workers.

Abstract: 286 words

Text: 3570 words, including tables and figure captions

Introduction

In Britain there are over 300,000 construction companies employing 1.4 million workers; peak employment of around 1.6 million occurred in 2008. About 40% of these people are employed in the South East, London and the East of England (ONS, 2019). Exposure to solar ultra-violet (UV) radiation can cause skin cancer and in Britain each year there are around 1,500 cases of non-melanoma skin cancer (NMSC) caused by exposure to UV from sun exposure at work and there could be about 250 cases of malignant melanoma (MM) (Rushton et al., 2012; Rushton and Hutchings, 2017). Almost all of those diagnosed with NMSC are successfully treated, but around 20% of the MM cases die from their disease. Around 45% of the NMSC and 40% of the MM are attributable to exposure in the construction industry (Rushton et al., 2007). The risk for NMSC is thought to be related to cumulative UV exposure, generally measured as standard erythema dose (SED), while malignant melanoma is likely caused by intermittent and acute exposures that give rise to erythema (Milon et al., 2014). UV exposure has positive benefits, including synthesis of vitamin D in the skin, although during winter in Britain there is insufficient UV to produce vitamin D. Skin colour (phototype) is important in determining the erythema and skin cancer risk, and so is an important factor to consider in terms risk assessment.

Little is known about the magnitude of occupational exposure to solar UV in Britain (latitude 51.5-56N). Grandahl et al. (2018) describe measurements of UV exposure for Danish workers (latitude 55-57N). The median daily exposure they measured for outdoor workers throughout the summer months was 2.0 SED, for those who worked partly outdoors 1.1 SED and for indoor workers 0.5 SED. Thieden et al. (2005) compared the exposure of Danish (55.7N) and Irish (53N) gardeners during summer months and found higher exposures among the Danish workers: median 1.6 vs 1.0 SED. Peters et al. (2016) carried out a similar investigation among Canadian (latitude 47N) outdoor construction workers, measuring exposure of 73 workers (318 measurements); the geometric mean exposure was 1.18 SED, with a geometric standard deviation of 3.84. There have been no measurements of UV exposure amongst British outdoor workers.

Previous research in the British construction sector has shown that sun-safety is poor and that an educational intervention using video materials could improve behaviour (Houdmont *et al.*, 2016). This research also showed that commitment to a good sun-safe culture by employers and the regulator (the Health and Safety Executive) would further enhance effectiveness of interventions. Typically, these interventions are based around education or training programmes promoting actions such as covering-up, use of sunglasses, brimmed hats and sunscreen.

There is no opportunity for construction workers who suffer from skin cancer to seek compensation through the Industrial Injuries Disablement Benefits scheme, which requires a more than doubling of risk in epidemiological studies, e.g. a relative risk estimate of two or more, as a way of identifying situations where work is more likely than not the cause of the disease. The UK Industrial Injuries Advisory Council reviewed the scientific evidence of risk relating to the two main types of NMSC (IIAC, 2018): basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). They concluded that the risks of BCC and SCC are increased by outdoor work and there is a doubling of risk for some groups, the evidence mostly comes from studies in countries at lower latitudes than those in the UK with higher UV exposure. They were therefore unable to recommend prescription for NMSC in relation to occupational exposure to solar UV.

The aim of this paper is to summarise measurements of erythema-weighted UV radiation exposure amongst construction workers in Scotland and the Southeast of England collected during an intervention study. The data are discussed in terms of the risk of NMSC amongst construction workers and the additional steps needed to prevent disease.

Methods

The UV measurements reported here were part of a larger intervention study that aimed to investigate whether the combination of short messages delivered to the smartphones of construction workers, along with appropriate organisational support, could influence the workers' behaviour to reduce exposure to UV radiation among those at risk of excessive exposure (in the study this was designated as the 'high UV wave', which was targeted between April and September). The study also investigated vitamin D intake during winter (the 'low UV wave' targeted between October to March), but this aspect of the intervention is not reported here. The study protocol has been published in the scientific literature (Nioi et al., 2018). Further details of the full study are published elsewhere (Lansdown et al., 2019; Nioi et al., 2019). Ethical approval to carry out this research was granted by Heriot-Watt University Engineering and Physical Sciences, Research Ethics Committee (approval number 2016-164).

Construction sites were opportunistically recruited into the study from Central Scotland and Southeast England. Volunteer workers were recruited into the study following an information presentation. The eligibility criteria were: adult male or female employees in the construction industry, living in Britain, either predominantly indoor or outdoor workers (based on self-reported work pattern) and owning a mobile phone, with no restriction on age or ethnicity. Participants were randomised to the intervention at site level and completed both control and intervention conditions. Recruitment was for three study periods of data collection (waves) each lasting 21 days, although in this paper we only report data from the second phase of the study (we use the term “Summer” to describe the higher UV period, although the measurements were made between mid-April and July). Participants completed a socio-demographic profile, including age, gender, occupation, ethnicity and self-reported skin type. Knowledge of sun-safe behaviour and vitamin D was recorded using a short questionnaire.

At site level participants were initially randomised to either the control (Ctrl) or intervention (Intr) groups for the initial winter data collection. The intervention group from the first low UV wave was the control group in the high UV wave and the control group in the second low UV wave. Where it was not possible to retain the same participant at a site between data collection waves, due to change of job or some other reason, a substitute participant was recruited.

The intervention was delivered to the workers using a mobile phone short message service (SMS). A daily message was sent to participants, tailored to reflect season and local weather conditions to encourage preventative behaviours. A supportive phone app contained information about forecast UV levels at a specific location (automatically identified by the phone location), sun-safe actions and sources of vitamin D. During the control periods participants did not receive the daily intervention text message or prompts to view the sun-safe and healthy behaviour App.

25-hydroxy-vitamin D (25(OH)D) concentrations in blood were measured by high-performance liquid chromatography using dried blood spots obtained with a self-administered sampling kit (uncertainty of the analysis typically <5%). These samples were collected at the start and end of each phase of the study. Results were emailed to participants and the research team. Data were presented along with the reference intervals and vitamin D status. The reference intervals used by the analysis laboratory were (1) <15nmol/l = Severe Deficiency, (2) 15-30nmol/l = Deficiency, (3) 30.1-50nmol/l = Insufficiency, and (4) >50.1 nmol/l = Adequate (www.cityassays.org.uk).

Participants were issued with a UV (230-320nm erythema-weighted) wearable sensor, that was capable of logging measurements throughout the day (Scienterra UV Badge, www.Scienterra.com). The uncertainty of the sensor is reported by the manufacturer as less than 5%, and data from others support the suitability of this sensor (Corradi et al., 2019). Logged data were converted to measures of standard erythema dose (SED) over a workday, where 1 SED is equivalent to an erythema radiant exposure of 100 J/m^2. It is a cumulative measure, which involved multiplying the erythema weighted irradiance by the time intervals between measurements (two-minutes) and accumulating these together for a work shift (eight hours). This measure is independent of skin type. To avoid the sensor being covered by the workers overall sleeve, each participant wore the sensor mounted on the rear of their hard hat rather than on the wrist, as has been done by other researchers. In a separate exercise, data were collected to compare exposure measurements on the wrist and head of one individual over 20 days.

Differences between start and end levels of vitamin D were calculated for each participant. Comparison of change in 25(OH)D between the intervention group and the control group used a two-group t-test to determine whether there was a statistically significant difference between the groups. Levels of change in 25(OH)D were also examined in relation to responses to the questionnaires, using multiple linear regression methods. Potential explanatory variables were included in the models singly and simultaneously to determine if there was any confounding or interaction between the variables. UV levels were also compared between the intervention and control groups using two-group t-tests and the association between UV exposure and potential explanatory variables was examined using multiple linear regression methods. In particular, UV exposure levels were compared between workers at sites in the North and South of Britain, and between workers who worked predominantly indoors or outdoors. The regression analyses also tested for possible interactions between the explanatory variables.

Results

Table 1 summarises the number of sites in each location and the number of subjects assigned to the intervention and control. The table includes only those participants who provided blood samples. Nine sites participated (five in Scotland and four in or around London). From the original cohort, 61% of participants returned to participate in the summer data collection. The largest percentage of participants were aged between 31 and 50 years and were predominantly male (96.7%) and of white British ethnicity (73.8%). Fifty four percent were site operatives, 41% on-site professionals and the remainder were deployed in other jobs. Around 80% of the participants in Scotland reported their skin colour as ‘fair’, but the corresponding figure in SE England was 53%.

From the 25(OH)D analysis the majority of workers were at sufficient levels of vitamin D during summer; only three individuals (5%) had a measurement ≤30 nmol/l (classified as “deficient”) at the start of the measurement period. The median and mean 25(OH)D levels were higher in the northern sites (median 83.0 nmol/l vs 74.6 nmol/l). This may reflect differences in skin colour or some other aspect of the work, for example time spent outdoors. In Scotland 17% of participants reported olive, brown or black skin colour whereas the corresponding figure in the southern sites was 40% (Table 1).

Change in vitamin D over the measurement period was investigated using multivariate linear regression analysis. The following potential explanatory variables were included in the model: Age, Gender, North/South site, Indoor/Outdoor worker, and Intervention/Control group. Specific responses to the questionnaire were also included, these were: ‘*Have you had skin cancer?’, ‘Have you been on holiday in a sunny country during the study?’, ‘Have you used a tanning sunbed during the study?’, ‘Have you regularly taken vitamin D supplements during the study?’, ‘If we gave you vitamin D supplements, would you take them? Since the start of this study have you bought any fortified vitamin D products or bought more food rich in vitamin D?* Terms were fitted one at a time in separate models and, where more than one term was statistically significant then these terms were included simultaneously in the model to investigate any confounding or interactions.

The only significant variable was Intervention versus Control groups, which showed that the change in vitamin D levels was greater in the Intervention group (there was a small increase in vitamin D in the intervention group and a decrease in vitamin D in the control group). This was contrary to the study hypothesis. There was also some evidence of a difference in change in vitamin D in those who had taken a holiday in the sun during the study period and those who had not, with a large decrease in vitamin D in those taking a holiday and a small decrease in those who had not (Table 2), although only seven of the 54 participants took a holiday, and so it is difficult to draw any firm conclusions from this finding.

Erythema effective UV radiation exposure data was available for 41 participants, representing 758 working days. Figure 1 shows the distribution of SED subdivided by intervention and control group and by predominantly indoor and predominantly outdoor workers. Daily SED ranged from 0 to 13.47; average daily SED by individual ranged from 0.0043-4.14. On average, levels were higher in outdoor workers than indoor workers and higher in the intervention group than in the control group, the latter finding is consistent with the 25(OH)D data, which was also higher in the intervention group.

Multiple linear regression analysis was carried out to investigate the association of UV levels with potential explanatory variables: Age, Gender, Skin type, North/South site, Indoor/Outdoor worker, Change in 25(OH)D across Wave 2, Ethnicity, and Intervention/Control group. Responses to the questions – from the questionnaires, '*Have you had skin cancer?*', and I '*Avoid/Minimise work in summer sunlight in the middle of the day*' were also included as potential explanatory variables. Again, terms were fitted one at a time in separate models, and, where more than one term was statistically significant then these terms were included simultaneously in the model to investigate any confounding/interactions.

Only indoor/outdoor working was significantly associated with UV exposure, with UV levels higher in outdoor workers (model 1, Table 3). However, differences were seen between the Intervention and Control groups after adjustment for Indoor/Outdoor working, with levels in the Intervention group being statistically significantly higher (model 2, Table 3). It is notable that despite the outdoor UVB irradiance from satellite data being higher in the southern sites than in Scotland, there was no statistically significant difference in the corresponding personal exposure data.

In the separate exercise to compare UV measurements on the wrist with measurements made on the back of the head, as was done in this study, twenty pairs of daily measurements were made by the same individual. The values ranged from 0.2 to 2.3 SED on the wrist and 0.1 to 1.2 SED on the head. The mean ratio of head to wrist data was 0.68. The measurements on the two body locations were poorly correlated ($r^2 = 0.08$).

Discussion

The intervention had a small positive effect on increasing knowledge about the risk of skin cancer from sun exposure and, generally, there were good levels of awareness of the harm that may be caused by overexposure to the sun (Nioi et al., 2019). The higher 25(OH)D levels and higher measured personal UV exposure in the intervention group were not as anticipated and demonstrate that the intervention was unsuccessful. It is unclear why this was the case or why the 25(OH)D and UV measures were higher in the intervention group, but it is notable that many of our participants had a positive attitude to being suntanned. In the questionnaire responses 75% of participants agreed with the statement, ‘I like to have a suntan’. As Hiom (2006) has noted, questionnaire surveys have clearly shown the British as a ‘nation of sun lovers reluctant to cover up or find shade, especially when on home soil’. The expressed attitudes to harmful ‘sun seeking’ are predominantly associated with younger people, particularly those under 45 years. Around 46% of people surveyed felt ‘a suntan makes me look more attractive’ and about 60% reported ‘a suntan makes me look healthier’ (Hiom, 2006). It is clear that a more sustained approach is needed in Britain to change perceptions of sun-tanned skin.

A small number of studies of occupational UV exposure that have been undertaken, but ours is the first study of British workers. We found that in summer, construction workers who predominantly worked outdoors were exposed to on average 2.0 SED and those who worked partly indoors and partly outdoors 0.7 SED. In the outdoor workers around 40% of the daily exposures exceeded 2 SED while about 12% of the exposures for the indoor workers were above 2 SED, which can cause erythema in fair-skinned people. These data are consistent with data from studies in countries of comparable latitude, i.e. Danish outdoor workers median 2.0 SED (Grandahl et al., 2018), although direct comparison with the data in the present study is confounded by differences in the measurement location on the body.

Our measurements were made on the rear of the head of the subjects (hard-hat), although most other studies have measured exposure on the wrist. Serrano and colleagues (2013) made measurements of UV exposure on different body locations and found the difference between the wrist and shoulder were not statistically significantly different. However, measurements at various anatomical sites have illustrated how solar UV exposure varies over the body in different conditions; for example, Wright *et al* (2004) showed that the exposure on the top of the head was around 50% higher than the back of the hand under clear skies and about 27% higher on overcast days when indirect UV radiation makes up a greater part of overall exposure. Exposure at a body site may vary with environmental conditions, e.g. solar azimuth, and behaviour or body orientation (Weihs et al., 2013). Clearly this needs to be considered when comparing measurements made with different strategies, although it is not straightforward to correct for sampling body location. In future measurement studies, it would be prudent to collect data from more than one body location, e.g. wrist, chest and rear of head, particularly as in our study we found little correlation between measurements at the different body locations.

Epidemiological studies among outdoor workers have demonstrated a clear increased risk for both SCC and BCC, although there are few studies that have quantified the risk of skin cancer in relation to exposure. However, two recent case-control studies from Germany quantified UV exposure using a job-exposure matrix to estimate exposure representative of the chest (Schmitt, 2018a; Schmitt, 2018b). They found a doubling of the risk for SCC for a lifetime occupational exposure of 6,348 SED, with the corresponding figure for BCC being 7,945 SED. Someone who worked in an outdoor job in Britain for about 30 to 40 years with an annual exposure of around 200 SED on unprotected skin , or about 2 SED on working days when there was potential exposure to solar radiation (i.e. about 6 months each year, i.e. 100 working days), would accumulate around 6,000 to 8,000 SED. This would suggest that outdoor construction workers in Britain who worked more than about 30 years could have a doubling of risk for SCC and those working outdoors for more than about 40 years could have a doubling of risk for BCC.

Clearly, we need to act to protect outdoor construction workers in the UK, and elsewhere. Others have recently advocated action to strengthen workplace sun-safety and recognise the burden of non-melanoma skin cancer from outdoor work in Europe (John et al., 2019). Reliance on training and behavioural interventions, such as the one evaluated here, are most probably insufficient. We suggest that construction employers need to take a more proactive approach to managing sun safety and enforce the use of necessary protective measures, both personal protection and modification of work processes to minimise exposure. Use of sunscreen should not be the main protective measure relied upon. Currently sun safety is seen as an issue of personal choice for workers, with the role of the employer being to promote good practice. For example, guidance from the regulator in Britain emphasises employers should provide training, 'encouraging' workers to cover up and use sunscreen, and to 'consider' organising work to minimise exposure (HSE, 2001). We suggest the regulator should have a stronger role in promoting a risk-based management approach to UV, which we believe is already required under the provisions of British health and safety legislation. In general, health surveillance appears to be left to the discretion of workers, as if this were a public health issue. In our opinion, health surveillance of outdoor workers to detect skin cancer is also currently a legal obligation on employers.

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Figure captions

Figure 1 Boxplot of distribution of daily SED

The box extends from the 25th to 75th percentile, with the horizontal line within the box indicating the median level. The lines outside the box extend from the 10th to the 90th percentile, with values outside these values displayed as individual points.

Table 1 Study overview

Location	**Control sites**			**Intervention sites**		
	Sites (Subjects)	Skin colour		Sites (Subjects)	Skin colour	
Scotland	3 (17)	Fair Olive Dark brown/black	14 3 0	2 (12)	Fair Olive Dark brown/black	9 3 0
SE England	2 (18)	Fair Olive Dark brown/black	7 9 2	2 (14)	Fair Olive Dark brown/black	10 4 0

Table 2 ***Mean change in 25(OH)D (nmol/l) during Wave 2 with standard error (s.e.) and number of measurements (n)***

Group	**Holiday**			**No holiday**			**Total**		
	Mean (nmol/l)	s.e.	n	Mean (nmol/l)	s.e.	n	Mean (nmol/l)	s.e.	n
Control	-24.8	(10.6)	6	-8.9	(4.5)	26	-11.9	(4.2)	32
Intervention	-42.1	(-)	1	5.6	(3.6)	21	3.4	(4.1)	22
Total	-27.3	(9.3)	7	-2.4	(3.1)	47	-5.6	(3.2)	54

Table 3 ***Regression analysis of the UV exposure data***

		Model 1			Model 2		
Outcome variable	**Explanatory variable**	**Co-efficient**	**Standard error**	**P-value**	**Co-efficient**	**Standard error**	**P-value**
	Constant	0.690	0.208	0.002	0.326	0.243	0.188
	Outdoor v Indoor[1]	1.319	0.280	<0.001	1.487	0.270	<0.001
	Intervention v Control[2]				0.688	0.274	0.017

[1] Coefficient represents increase in UV in outdoor workers compared to indoor workers

[2] Coefficient represents increase in UV in the Intervention group compared to the Control group

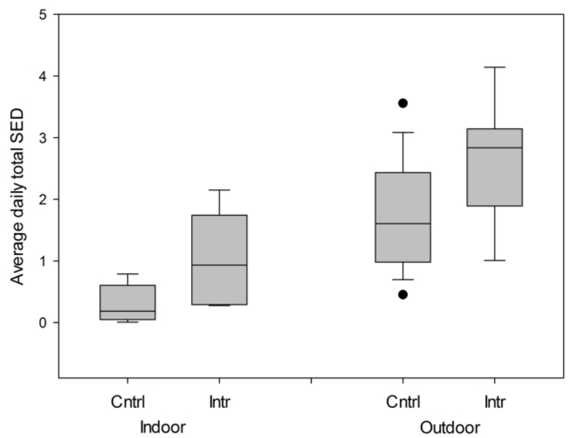

Figure 1 Boxplot of distribution of daily SED
The box extends from the 25th to 75th percentile, with the horizontal line within the box indicating the median level. The lines outside the box extend from the 10th to the 90th percentile, with values outside these values displayed as individual points.

209x296mm (300 x 300 DPI)