Solar Ultraviolet Radiation Exposure and Sun Protection Behaviours and Knowledge Among a High Risk and Overlooked Group of Outdoor Workers in South Africa

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ABSTRACT

The exposure of outdoor car guards to solar ultraviolet radiation (UVR), the majority with deeply-pigmented skin, to solar UVR was measured for five consecutive days during early spring (September 2017) in South Africa using electronic UVR dosimeters attached to the upper arm of each participant. The exposure of the nape of the neck, forehead, nose, cheek and hand were extrapolated from the measurements. The onsite ambient solar UVR on a flat, horizontal, unshaded surface was measured concurrently. The sun-related knowledge, behaviour and attitudes of the car guards were evaluated using questionnaires. Total personal daily solar UVR exposure as a percentage of the ambient solar UVR exposure was 24%. The exposure of car guards on several body sites was in excess of the occupational threshold limit value (TLV). Sleeved shirts and hats were the most commonly used sun-protection measures (worn by 70% and 80% respectively). Considering the high levels of solar UVR reported on most days throughout the year in South Africa, more studies quantifying the personal exposure of outdoor workers in both the informal and formal sectors are necessary.

INTRODUCTION

The sun is the main natural source of UVR. All living beings are exposed to solar UVR when in outdoor settings. Solar UVR is a known human carcinogen, linked to melanoma and non-melanoma [basal cell carcinoma (BCC) and squamous cell carcinoma (SCC)] skin cancers. [1] Experimental as well as epidemiological studies have reported an association between solar UVR exposure and skin cancers. [1, 2] In South Africa, non-melanoma skin cancers are among the cancers with the highest reported incidence in both males and females. [3] The main risk factor for non-melanoma skin cancers, especially SCC, is cumulative solar UVR exposure. [4] Outdoor workers are subject to high cumulative exposure when compared to the general population. A relationship between outdoor work and non-melanoma skin cancers has been established and reported. [5, 6, 7]

Excess solar UVR exposure also induces sunburn, skin photo-aging, immunosuppression and eye disorders such as photokerato-conjunctivitis, pterygium, ocular surface squamous neoplasia, droplet keratitis and cataracts. [4, 8, 9, 10] The risk of skin effects differs for all humans. More specifically, individuals with fair (lighter) skin types are at higher risk of negative skin effects because they have less protective melanin when compared to individuals with darker skin types. [8] The effects on the eye and immune system are independent of skin type and thus the risk is the same for all humans. [11]

In most outdoor occupations, the workers are not at liberty to perform their work in shaded or sunny areas. Studies quantifying personal exposure of outdoor workers in different industries have shown that workers are exposed to high levels of solar UVR, defined as levels above the International Commission on Illumination (CIE) Threshold Limit Value (TLV) of 1.09 SED. [12, 13, 14, 15] In a South African case study, an outdoor worker was exposed to

84% of the total daily ambient solar UVR. [15] This implies that, depending on the ambient solar UVR levels, an outdoor worker of any skin type is likely at risk of sunburn on many days of the year. The actual risk for each individual will depend on skin photosensitivity and sun-protective practices. However, a number of studies have reported poor sun-protective practices among different groups of outdoor workers. [12, 16, 17]

Car guards are either formal or informal workers who serve to safeguard cars parked in car parks. Information on occupational health issues that car guards face is scarce suggesting that car guarding is an occupational group that is overlooked. To date, there is only one study which evaluated the solar UVR exposure of a car guard and it was found to be high. [18] South Africa has no legislation governing exposure to solar UVR, nor does it have an Occupational Exposure Limit (OEL) for exposure to solar UVR. The Occupational Health and Safety Act (Act 83 of 1993) states that an employer has to provide and maintain, as far as possible, a work environment that is safe and without risk to the health of the employees. [19] Workers in the informal sectors such as the study population may not be protected by the aforementioned law and they are responsible for their own health and safety.

The aim of the study was to measure the solar UVR to which car guards, essentially security workers who observe parked cars to prevent theft, are exposed during their working shifts, using electronic UVR dosimeters. The data were used to determine total daily solar UVR exposure, 10-minute exposure (SED/10 min), and personal exposure as a percentage of the ambient solar UVR measured on a flat surface – a common metric for comparison between studies of personal exposure. The data were also used to calculate exposure of other anatomical sites (specifically the nose, forehead, nape of the neck, cheek and hand) to solar UVR. The median solar UVR exposure level of all the car guards and the overall maximum exposure were also determined from the data. The personal exposures were compared to the TLV to assess whether or not car guards received solar UVR in excess of the TLV. Furthermore, the sun-related knowledge, behaviour, and attitudes of the car guards were evaluated using a questionnaire.

MATERIALS AND METHODS

Study area and design: The study was carried out in Potchefstroom, North West Province. This province forms the southern part of the Kalahari Desert, which receives sunshine almost all year round. The town of Potchefstroom has a latitude of 26°S, an altitude of 1 378 m and relatively clear skies throughout most of the year. Therefore, this area may receive substantial levels of solar UVR, placing individuals who spend extended periods outdoors, such as outdoor workers, at increased risk of high exposure. The specific location where the car guards worked (name withheld) had no form of shade, making this setting and these outdoor workers an ideal study population.

Study population: The car guards were employed, informally, by a security company and permission from this company was sought prior to implementation of the study. A working shift constituted 15 car guards eight of which gave consent to wearing dosimeters and 10 to filling in questionnaires. Participants who were eligible to take part in the study were those who were 18 years and older and worked day shifts of six or more hours for five or more days a week during the measurement period. This study was approved by the Health Research Ethics Committee (HREC) of the North-West University (Reference number: NWU-00039-17-A1).

UVR dosimeters and calibration: The electronic UVR dosimeters used in this study were from the Department of Electrical and Computer Engineering, University of Canterbury, Christchurch, New Zealand. These dosimeters are designed to measure erythemal UVR (280–

320nm) have on-board data logging as well as data download capabilities[12, 20]. While it would have been useful if the dosimeters measured the full UVR spectrum given the differences in UV-A and UV-B, this was a shortcoming of the dosimeter.

All of the dosimeters were powered by lithium coin cell batteries, which powered the dosimeters fully during UVR measurements and entered sleep mode outside measuring time. They were reusable, had a high sampling rate, did not saturate on daily measurements, had a linear response and recorded time-stamped non-integrated UV irradiance. The last-mentioned characteristic is important since changes in UVR exposure throughout the day are quantified.

The dosimeters were programmed to record measurements from 09:00 to 15:00 South African Standard Time (SAST) on each day at one-minute intervals. This interval was chosen because the UVR dosimeters are sensitive to frequent UVR changes, which may be brought about by a change in cloud patterns or solar zenith angle (i.e. the position of the sun in the sky relative to the horizon). [20] All of the UVR measurements stored in the electrically erasable programmable read-only memory of the dosimeters were downloaded at the end of data collection onto a computer using a USB link.

Using sunlight as a source of solar UVR, the UVR dosimeters were calibrated during the period of 24 – 28 August against the research-grade Solar Light 501 UV Biometer sensor at the Bolepi House, South African Weather Services in Pretoria (23.7°S, 28.2°E), South Africa. This Biometer detects solar UVR in the wavelength range of 280 nm – 340 nm and has erythemal UVR as an output. The levels recorded are reported in Minimal Erythemal Dose (MED), where 1 MED = 210 J/m^2 and for this study the MED values were converted to Standard Erythemal Dose (SED) (1 SED = 100 J/m^2).

For each dosimeter, calibration coefficients were calculated by fitting a second order polynomial function to the measures of the Biometer against the measures of the UVR dosimeter (An example for one instrument is given in Figure 1). The calibration coefficients - unique to each dosimeter - in its calibration equation were used to convert the counts obtained with the UVR dosimeter during the car guard measurement campaign to erythemal UVR units (in SED).

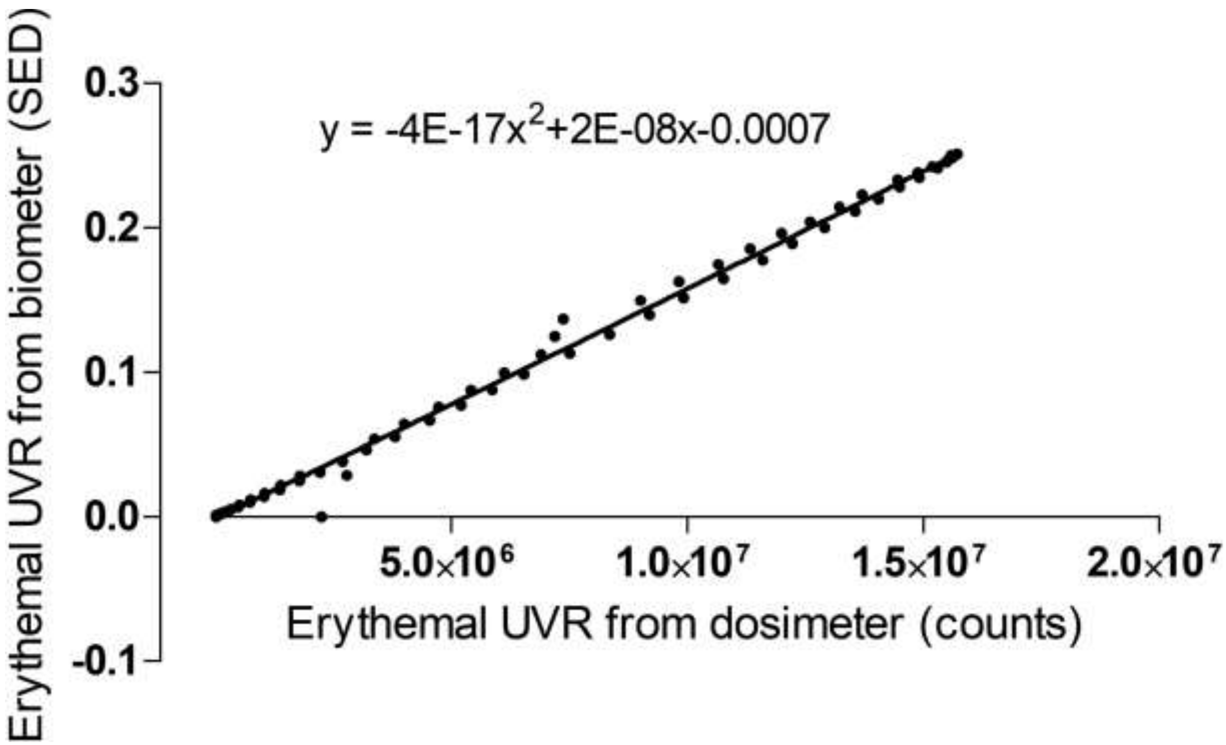

Figure 1. Dose-response function of erythemal exposure in counts from a dosimeter against erythemal exposure in SED from the Solar Light Pty Ltd 501 UV Biometer.

Procedure for personal exposure measurements: Using adjustable straps, all consenting participants were asked to attach an electronic dosimeter on the outer side of their left upper arm at the start of the shift . At the end of each shift, the dosimeters were removed from the participants and placed in an impervious container, where they were stored until the next day of data collection.

Procedure for measurement of ambient solar UVR: To determine the percentage of ambient solar UVR received by the participants, one dosimeter was placed on a flat, horizontal, unshaded area at the work site. Equation 1 was used to calculate the exposure of each participant as a percentage of ambient UVR:

$$Exposure\ as\ a\ percentage\ of\ ambient\ UVR = \frac{Personal\ exposure\ (SED)}{Ambient\ UVR(SED)} \times\ 100$$

(Equation 1)

In addition to measured ambient solar UVR data, daily solar noon Ultraviolet Index (UVI) data for the study days was extracted from NASA's Giovanni data portal from the satellite-based Ozone Monitoring Instrument (OMI) for comparison against the ground-based levels.

Questionnaires: The questionnaire used in this study was designed by the researchers and its content was validated pre-study. After providing written informed consent, all of the participants filled in a questionnaire, which was used to evaluate their knowledge, attitudes, and behaviour pertaining to solar UVR exposure. The data from the questionnaires were then recorded using the REDCap Software (Version 6.1.3) hosted at North-West University for analysis. [21]

Data analysis: All solar UVR exposure results were represented in SED, where 1 SED = 100 J/m^2 normalized to 298 nm. The exposure data were compared to the TLV of 1.09 SED effective dose of UVR per day, developed using the CIE action spectrum. [22] Exposure of other anatomical sites (i.e. forehead, nape of the neck, nose, cheeks and hands) was calculated using Equation 2:

$$TDE = \left(DE\ upper\ arm * \frac{100\%}{45\%}\right) * EPA\ of\ anatomical\ site \qquad \text{(Equation 2)}$$

Where:

- TDE is Total Daily Exposure to be calculated.
- DE is the Daily Exposure on the upper arm (site where dosimeter was attached).
- 100% is the exposure of the vertex as a percentage of the ambient solar UVR, while 45% is the exposure of the upper arm as a percentage of ambient UVR
- EPA is the Exposure as a Percentage of Ambient UVR for the anatomical site in question [23]

Statistical analyses: The statistical package SPSS IBM Corp (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp, 2013) was used to analyse the data. The distribution of continuous variables was tested for normality using formal tests, i.e. the Kolmogorov-Smirnov test and the ShapiroWilk test, and graphical methods, i.e. histograms and Q-Q plots. The median, minimum and maximum were used for reporting descriptive statistics. These were the only tests performed because the aim of the study was to evaluate the exposure of car guards to solar UVR during their working shift, in order to compare it with the TLV to determine overexposure and indicate any risk of acute effects using the exposure levels. Performing correlations and evaluation of the relationship between car guards' exposure and exposure sites was outside the scope of this study.

RESULTS

Characteristics of surrounding area and study population

At the shopping centre, there were brick buildings with painted corrugated iron roofing in the area where the participants worked. The horizontal surface of the area was asphalt concrete. The minimum distance between the participants and the buildings was about three to five meters, while the maximum distance was in the range of six to 15 meters. There were small trees in the work area. The basic demographics of the participants are given in Table 1 and the sun-related knowledge, behaviour and attitudes in Tables 3 and 4.

Table 1. Demographic characteristics of the study participants.

Variable	Scale used	***n* (%)**
Gender	Female	6 (60)
	Male	4 (40)
Age (Mean (range))	Years	39 (33–55)
Ethnicity	Black African	8 (80)
	White	2 (20)
Fitzpatrick Skin phototypes	VI to VI	8 (80%)
	I to II	2 (20%)
Level of education	No schooling	4 (44)
	Secondary (Grade 8-12)	5 (45)
	No response	1 (10)
HIV status	Negative	3 (30)
	Positive	1 (10)
	Do not know	4 (40)
	Do not want to say	2 (20)

Solar UVR exposure: ambient and workers

The total daily ambient solar UVR was recorded by dosimeters (Figure 2) where these readings varied considerably from the local noon ultraviolet index (UVI) values extracted from OMI for Potchefstroom during the study period (Table 2). The dry bulb temperature for the five days measured around solar noon ranged from 26 °C – 32.4 °C. Clear skies with no cloud cover were observed during the period of measurements.

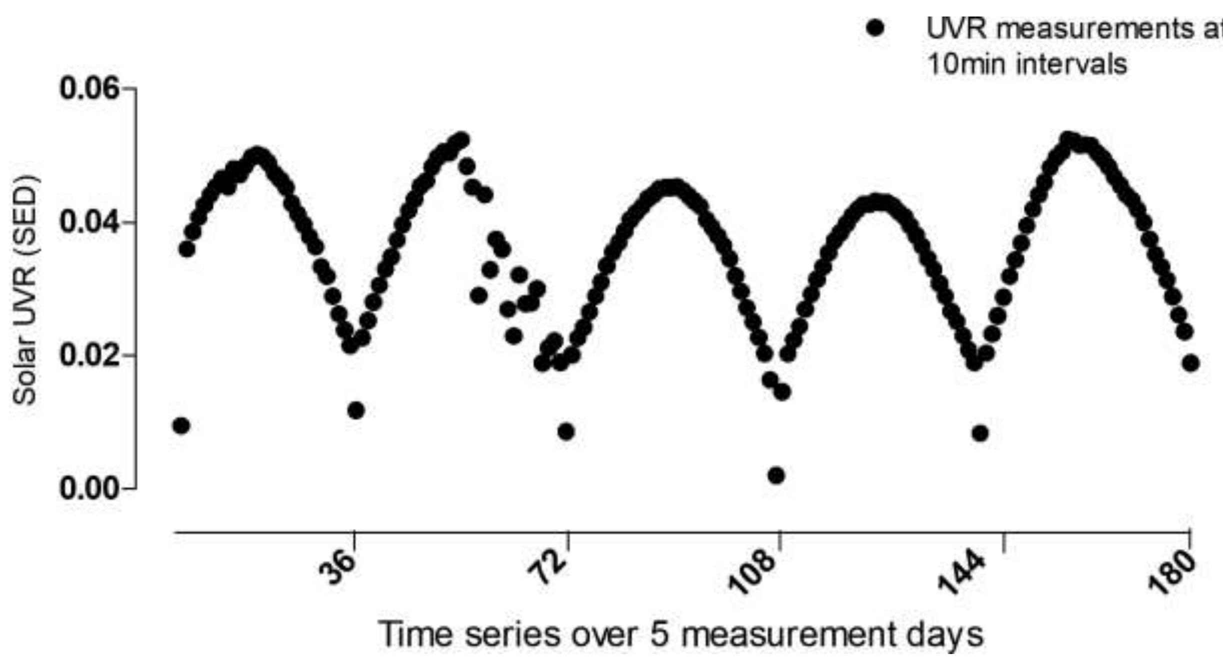

Figure 2. The onsite ambient day-time solar UVR (SED) in 10-minute time intervals from 18 – 22 September 2017. Night-time solar UVR values (of zeroes) are not shown.

Table 2. Measured and reported onsite daily ambient environmental conditions from 18 – 22 September 2017.

Date	Total onsite ambient solar UVR (SED)	Ultraviolet index values[$] converted to SED (SED)	Dry bulb temperature (°C)	Humidity (%)
18-09-2017	1.18	8.62	28.9	18.7
19-09-2017	1.26	8.86	26.0	22.6
20-09-2017	1.23	9.14	28.7	16.2
21-09-2017	1.14	9.48	28.3	23.4
22-09-2017	1.42	9.65	32.4	12.6

Note: SED, standard erythemal dose, and 1 SED = 100 J/m². The values for temperature, humidity and wet-bulb globe temperature (WBGT) index were measured using the 3M QUESTemp° 36 (S/N TEH040046). [$], From OMI, Giovanni.

The personal exposure of the car guards varied between the car guards and throughout the day (Figure 3). The personal exposure of most of the car guards followed the same pattern as the ambient solar UVR, with peaks occurring between 11:30 and 13:00. The maximum 10-minute personal exposure obtained from one car guard number was 0.07 SED at 12:20, while the maximum 10-minute ambient UVR was 0.24 SED at 12:10.

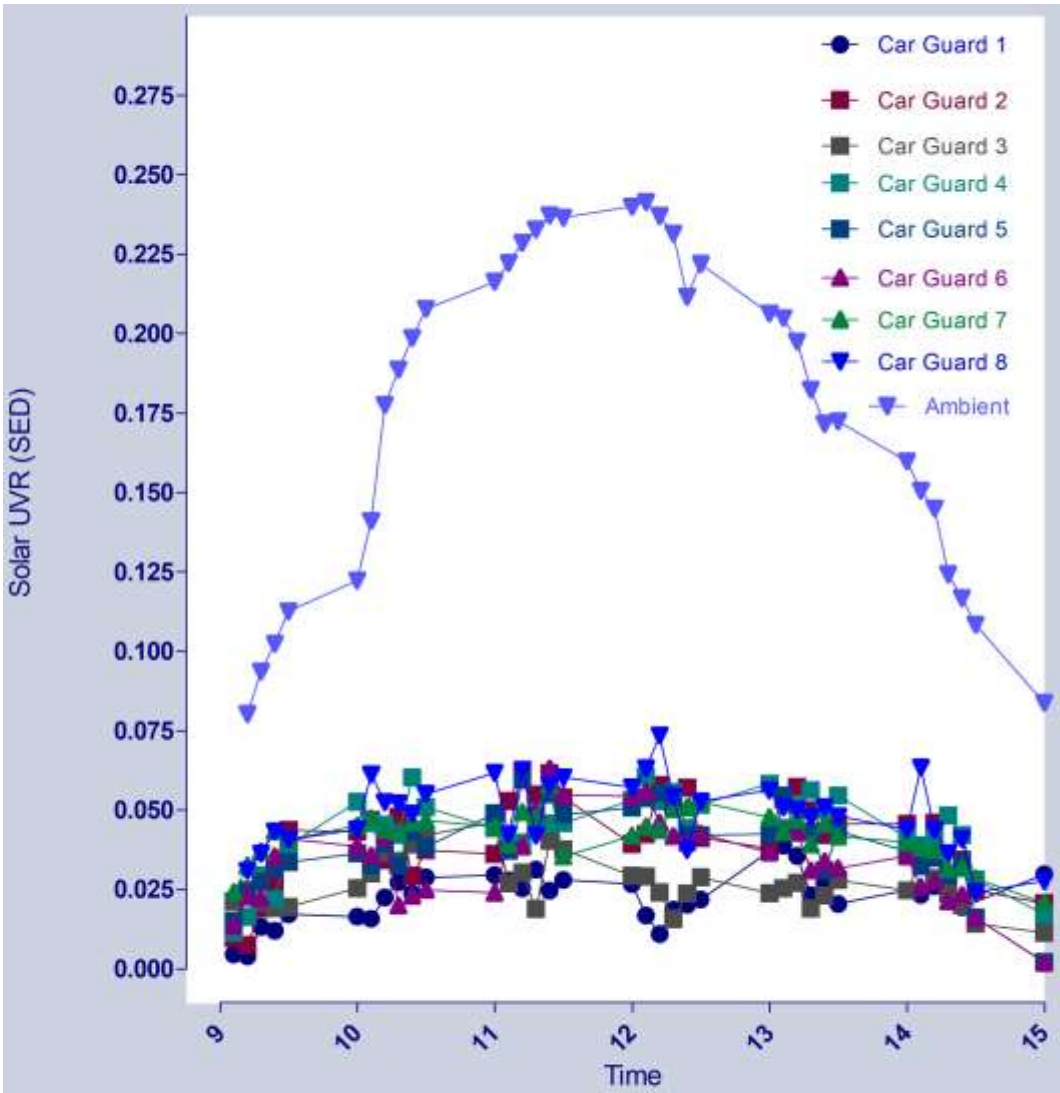

Figure 3. Average (of the 5 study days) daily personal and ambient solar UVR (SED) levels throughout the shift at 10-minute intervals

The total daily exposure on the upper arms of all the participants on all five days was lower than the TLV of 1.09 SED as defined using the CIE spectrum. The quantified median exposure of all the car guards over the five days was 0.29 SED with a maximum exposure of 0.63 SED.

Personal solar UVR exposure as a percentage of ambient UVR

The overall total daily solar UVR exposure of the car guards as a percentage of ambient total daily solar UVR was 24% (Figure 4).

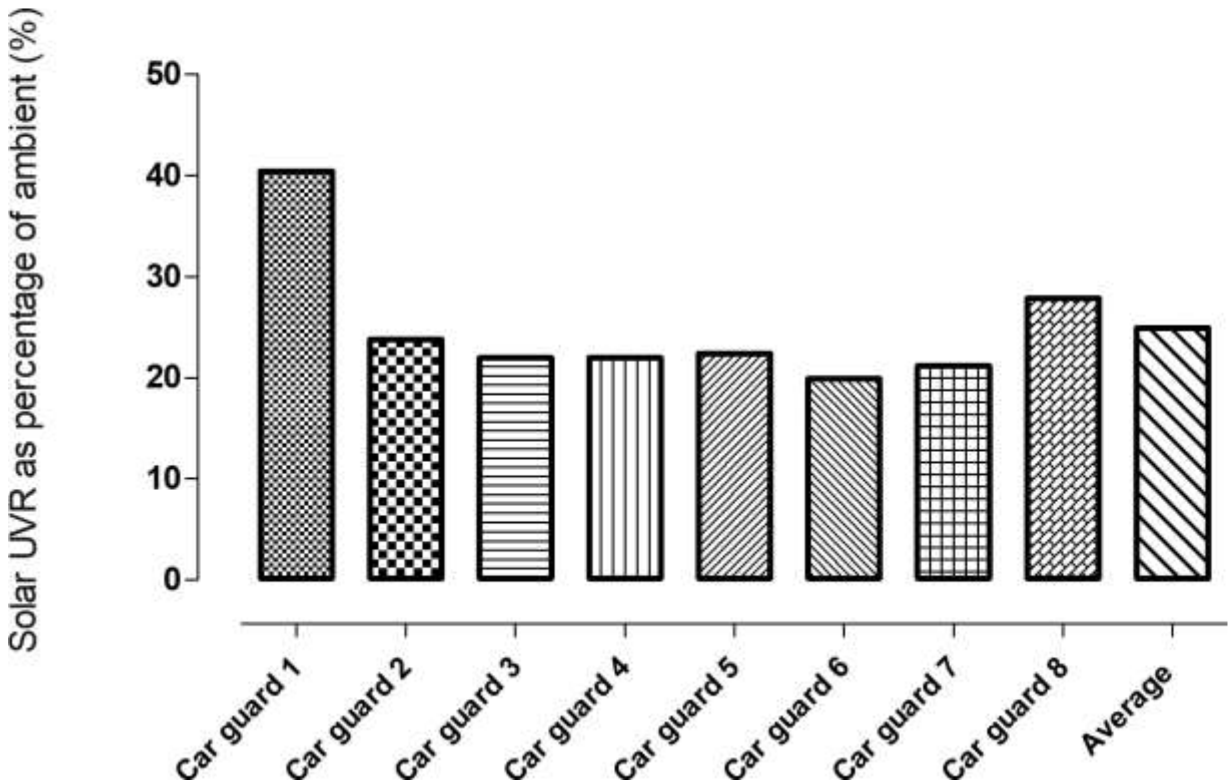

Figure 4. Solar UVR exposure of car guards as a percentage of ambient UVR and the mean percentage exposure as a percentage (%) of ambient solar UVR of all the car guards**.**

Estimations of solar UVR levels on other anatomical sites

Using anatomic site exposure ratios [23] we estimated potential solar UVR exposure at five other sites using our measured exposure at the upper arm. All of the estimated solar UVR levels on the anatomical sites, i.e. forehead, nape, nose, cheeks and hands, were higher than the levels that were measured on the upper arm and most were in excess of the TLV (Figure 5).

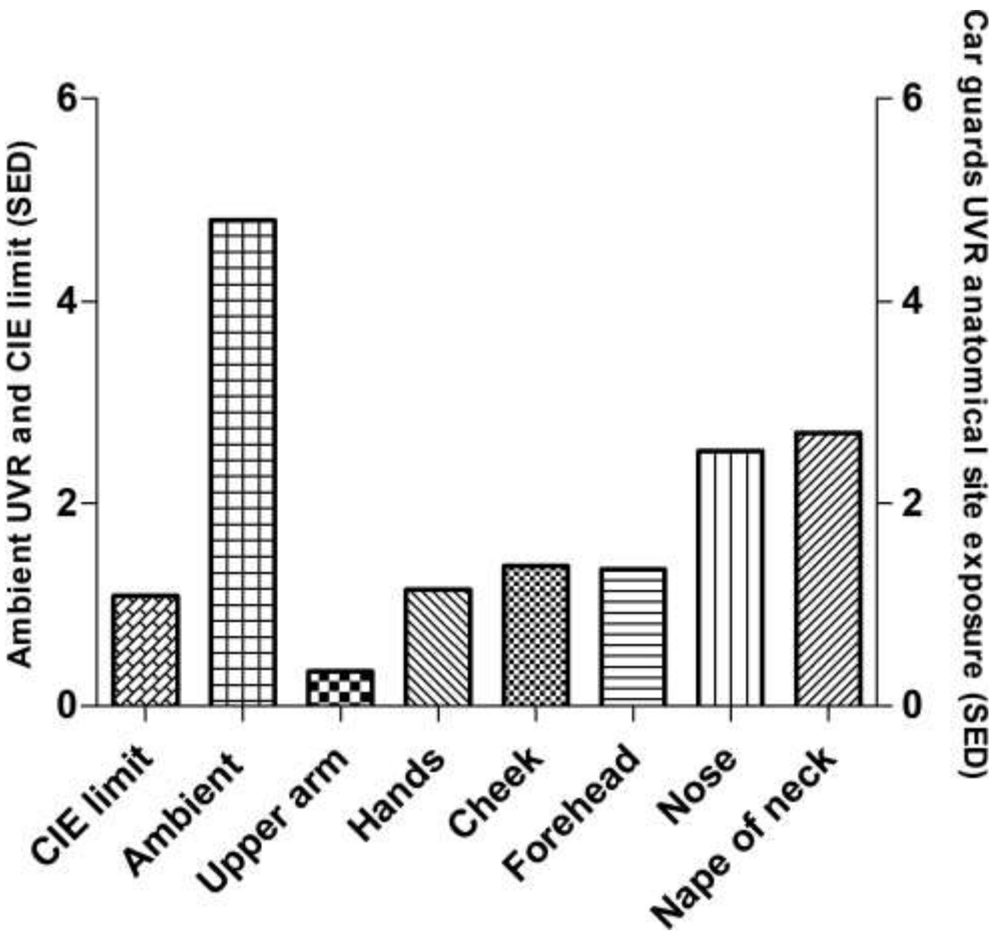

Figure 5. Solar UVR (SED) on different anatomical sites of car guards where the red line shows the TLV.

Sun-related behaviour, knowledge and attitudes

Sixty percent of the participants had worked in outdoor occupations previously for an average of four years and nine hours per day. Most of those (83%) had not received any sun safety education and training. The participants had been working as car guards for an average of eight years for six hours per day. All participants reported that they had never received sun safety education and training since they started working as car guards.

Table 3. Self-reported sun-related behaviour during work and leisure periods.

Behaviour	Scale used	Work *n* (%)	Leisure *n* (%)
Application of sunscreen	Never	7 (70)	8 (80)
	Sometimes	1 (10)	2 (20)
	Always	2 (20)	0 (0)
Wear a hat	Never	0 (0)	2 (20)
	Sometimes	3 (30)	5 (50)
	Always	7 (70)	3 (30)
Type of hat	Never	0	2 (20)
	Cap with back straps	0	1 (10)
	Cap with neck covering	0	1 (10)
	Baseball cap	1 (10)	4 (40)
	Wide-brimmed hat	8 (80)	3 (30)
	Beanie	1 (10)	0 (0)
Type of clothing worn	T-shirt short sleeve	1 (10)	3 (30)
	T-shirt long sleeve	1 (10)	2 (20)
	Shirt short sleeve	1 (10)	6 (60)
	Shirt long sleeve	5 (50)	2 (20)
	Coverall short sleeve	1 (10)	1 (10)
	Coverall long sleeve	3 (30)	1 (10)
Wear eye protection	Never	7 (70)	7 (70)
	Sometimes	1 (10)	2 (20)
	Always	2 (20)	1 (10)

Note: All values are in percentages (%), the total is not always 100% because some participants chose more than one option.

Three out of the ten participants reported that they were applying sunscreen on the face and arms (Table 3). Reapplication was only reported by two of the three participants. Seventy percent of the participants indicated that they never wore sunglasses when outdoors. Wide-brimmed hats were worn by 80%, while long-sleeved shirts were worn by 50% of the participants during working hours.

The majority of participants did not know the meanings of UVI and Sun Protection Factor (SPF) (Table 4). Sixty percent of the participants knew that the sun can affect the skin negatively; although skin cancer was the only known negative effect. Knowledge about the sun being hottest between 12:00 and 14:00 was reported by only four participants. Most participants knew the importance of protecting the skin using clothing and sunscreen, as well as the eyes with sunglasses, yet most reported that they did not wear eye protection or apply sunscreen when at work. Sixty percent of the participants did not know whether sunscreen was expensive or not, while 50% did not use sunscreen because they did not have time to apply it. The majority of the participants perceived dark skin as attractive, with 40% of these participants mostly the ones with light skin reporting that they sunbathed to darken their skin.

Table 4. Self-reported sun-related knowledge and attitudes

Sun-knowledge	**Scale used *n* (%)**		
	Yes	**No**	**I do not know**
People with dark skin have to use sunscreen?	4 (40)	1 (10)	5 (50)
People with light skin have to use sunscreen?	6 (60)	-	4 (40)
Do you know about Sun Protection Factor (SPF)?	2 (20)	7 (70)	1 (10)
The sun causes permanent damage to the skin?	6 (60)	4 (40)	-
Darker skin burns as easily as light skin?	2 (20)	3 (30)	5 (50)
People with dark skin suffer from sun effects?	1 (10)	4 (40)	5 (50)
The sun is a risk factor for skin cancer?	6 (60)	-	4 (40)
It is good to spend some time in the sun?	4 (40)	2 (20)	4 (40)
Do you know what Ultraviolet Index (UVI) is?	-	10 (100)	-
Have you received information about the sun?	-	10 (100)	-
It is important to apply sunscreen when outdoors	5 (50)	-	5 (50)
It is important to wear a hat	9 (90)	-	1 (10)
Long-sleeved clothes protect skin from the sun	9 (90)	-	1 (10)
Sunglasses are important to protect eyes from the sun	5 (50)	1 (10)	4 (40)
It is important to use available shade when possible	8 (80)	-	2 (20)
Sun protection is important in a vehicle	7 (70)	3 (30)	-
I am at risk of skin cancer	7 (70)	-	3 (30)
Attitude related questions			
I do not have time to apply sunscreen	5 (50)	5 (50)	-
Sunscreen is expensive	3 (30)	2 (20)	5 (50)
I enjoy time in the sun	4 (40)	6 (60)	-
Dark skin is attractive	3 (30)	7 (70)	-
I sunbath	4 (40)	6 (60)	-
I spend too much time in the sun	9 (90)	1 (10)	-
I worry about the sun when outdoors	9 (90)	1 (10)	-

Note: - Indicates no data were reported for the response.

DISCUSSION

Daily personal exposure to solar UVR as well as peak exposure time varied among the car guards and generally followed a similar pattern as the ambient solar UVR, although some car guards' exposure peaked either before or after peak midday ambient solar UVR levels. A similar pattern was found in a study among outdoor workers in New Zealand. [12] Total daily exposure of all car guards was below the TLV. Total daily exposure estimated for other anatomical sites, namely forehead, nose, cheeks, nape of neck and hands of the car guards, was higher than that measured on the upper arm most likely as a result of position and orientation in relation to the sun. [24] Although there was no risk of developing acute effects of solar UVR such as sunburn on the upper arms, the risk was likely present for other anatomical sites such as the forehead, nape of the neck, nose, cheeks and hands, depending on orientation in relation to the sun and clothing coverage. Previously, one car guard was found to be exposed to high levels of solar UVR throughout his working shift [18]. Among other types of outdoor workers, such as farmworkers, daily mean exposure to solar UVR of farmworkers was 1.21 SED (median = 1.16 SED) with a maximum daily exposure of 1.62 SED. [25] Although the previously mentioned studies were also conducted in South Africa, comparing the findings to our study is challenging because of differences in regions (altitudes and latitudes), seasons in which the solar UVR was quantified, areas of work (that influence albedo effects), type of dosimeters used as well as differences in the anatomical sites chosen for the attachment of dosimeters.

Interestingly, exposure of car guards as a percentage of ambient solar UVR at 24% was higher than the 20% hypothesized in an earlier study, [26] albeit lower than the 84% [15] and 46% [25] reported before. Construction workers in Spain were found to receive a median of 13.9% of the total daily ambient solar UVR [13] and outdoor workers in a New Zealand study received 20.5% of the total daily available ambient solar UVR. [12] Considering the high levels of solar UVR reaching the surface of South Africa, car guards are likely at risk of overexposure, in particular during summer, and experiencing adverse effects of solar UVR on days with very high or extreme ambient solar UVR levels. Moreover, car guards do not have any breaks during their shift implying therefore that their cumulative daily exposure exceeds that of other outdoor workers who have breaks spent in shaded areas. Generally, the practice of using shade and protective clothing can reduce the levels of solar UVR received by exposed individuals as well as the risk of related adverse health effects. [27] All of our participants used some form of sun protection such as sleeved shirts, wide-brimmed hats or baseball caps during work hours. Similarly, Carey *et al*. (2014) found that clothing (80.4%) and hats (72.2%) were the most frequently used sun-protective measures among a group of Australian workers [28] while among outdoor construction workers hats were used by 79% of workers and sleeved shirts by 82% of workers. [29] Consistent with other studies, the least used sun-protective measures were sunglasses and sunscreen. [29,30,31] This may be because participants do not know that the sun can have adverse effects on the eyes, since the skin was the only organ reported to be affected negatively by the sun. Majority of participants do not know the importance of applying sunscreen when outdoors and perceive that sunscreen is not affordable for them.

Receiving information and training has been proven effective in improving the knowledge as well as attitudes of outdoor workers. [31] The security company to which the car guards are independently contracted (informally employed) never gave the car guards sun safety information and training when they started work. In a systemic review, majority of workers in outdoor occupations were reported to have limited or no knowledge about the sun and its effects. [32] The UVI is a tool that was developed to inform the public about the intensity of solar UVR as well as to give advice on protective measures. [33] None of our study participants had heard or knew about UVI as was the case for the majority of German outdoor workers. [33] In contrast, about 77% of South African adults working at one of the biggest research companies in South Africa knew about UVI [34] although most of those workers might have had a higher socioeconomic status when compared to outdoor workers in this study.

Most of the participants in this study (60%) knew that spending extended periods outdoors exposed to the sun is a risk factor for skin cancer and perceived themselves at risk of skin cancer similar to70% of landscapers who considered themselves at risk of skin cancer. [35] Purposeful risk behaviour in our study was low; this was similar to a previous South African study that showed few South African adults, especially those with deeply-pigmented skin, sunbath regularly to darken their skin [34] in contrast to most international studies that report adults often do engage in tanning practices. [17,36,37]

This, to our knowledge, was the first study to quantify the exposure of car guards to solar UVR over several days and the first to evaluate sun-related knowledge, behaviour, and attitudes of outdoor workers in South Africa. For outdoor workers, cumulative exposure is also important, implying that all workers irrespective of solar UVR exposure levels measured during the study period are at risk of chronic solar UVR effects such as SCC and eye disorders. Personal exposure of the car guards as a percentage of ambient UVR was quite high, considering the high UVI levels that are reported throughout most days of the year in the town of Potchefstroom. With this percentage, exposures above the TLV can be expected on days with high UVI levels. In follow-up studies, the exposure of a larger group of car guards to solar UVR throughout the year should be evaluated. Concurrent behaviour using self-administered diaries should be incorporated. The measured onsite ambient solar UVR was low when compared to the reported UVI values.

Therefore, instrumentation bias is suspected and follow-up studies are needed to validate the findings of this study.

The car guards maintain better sun-protective practices when at work compared to outdoor workers in other studies. This may be attributed to the fact that the protective measures used at work (sleeved shirts, wide-brimmed hats as well as long trousers) are part of workplace uniform requirements. Studies evaluating the use of clothing and hats among informal outdoor workers will provide information as to whether the use of protective clothing and hats is voluntary or employer-led. The provision of sun safety education and training in the workplace is a necessity if the knowledge of the car guards about the sun and its effects is to be improved.

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