Seasonal trends in potential sunburn risk among outdoor workers in South Africa using monitored ambient solar UV radiation levels

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ABSTRACT
Exposure to solar ultraviolet (UV) radiation is an occupational health and safety issue. Excessive personal exposure is associated with adverse health effects, including skin cancers and eye conditions. Sunburn is a proxy for acute sun exposure and is implicated in skin cancer aetiology. To estimate national potential sunburn risk among outdoor workers, monitored ambient solar UV radiation levels at six sites across South Africa were converted into possible outdoor worker solar UV radiation exposures, calculated as 20% of total daily ambient solar UV radiation, by skin type and season. Mean total daily ambient solar UV radiation levels exhibited typical seasonal patterns with highest values during summer and late spring. Outdoor workers with skin types I, II and III (ranging from extremely to moderately sensitive) were identified as being at greatest risk of sunburn all year-round. Outdoor workers with skin types IV, V and VI were at risk during summer, spring and autumn. Real-time personal exposure monitoring of outdoor workers as well as information on skin cancer incidence among outdoor workers is required to better understand local exposure patterns and sun-protective practices to inform sun awareness campaigns.

Key words: solar ultraviolet radiation, outdoor workers, sunburn, risk

INTRODUCTION
For humans, sun exposure has both positive and negative health effects. Some sun exposure promotes vitamin D production. Skin cancers, i.e. non-melanoma and melanoma skin cancers, are the two most commonly experienced adverse health effects. Non-melanoma skin cancers are seldom fatal; however, they may be disfiguring and painful. Melanoma is fatal if undetected sufficiently early enough for treatment. According to the most recently available and reported National Cancer Registry records, melanoma and non-melanoma skin cancers account for approximately 30% (~ 35 000 cases in 1998 and 1999; 7000 melanomas and 28 000 non-melanoma skin cancers) of all histologically-diagnosed cancers in South Africa. Sunburn is a proxy for acute sun exposure and is implicated in skin cancer aetiology. Ocular sun exposure is also a concern and related health outcomes include cataracts and pterygia. Emerging health concerns include the impact of excess solar UV radiation on immune response as well as on the efficacy of vaccinations.

The relationship between sun exposure, sunburn and skin cancer is complex. Chronic exposure is generally associated with non-melanoma skin cancers, while the relationship between sun exposure and melanoma is more tenuous. Individual risk is also determined by the amount of melanin in human skin affording some natural protection against the harmful effects of excess solar UV radiation. Table 1 provides an indication of the risk of sunburn depending on melanin content and exposure to the sun according to six phototypes. Individuals with minimum natural protection, i.e. melanin, including fair-skinned individuals and albinos, and those spending extended periods of time outdoors, such as outdoor workers, and without sufficient sun protection, may be at risk.

Personal sun exposure is influenced by, among other factors, timing and duration of exposure, type of activity, body position and use of sun protection. In 2007, the World Health Organization emphasised the need for adequate protection of outdoor workers from solar UV radiation. Outdoor workers...
are particularly susceptible to the effects of non-melanoma skin cancer and ocular diseases because of the regular and prolonged nature of their sun exposure. The nature of occupation and use of personal protective equipment are also important factors. While their total risk is a combination of occupational and recreational sun exposure, workplace exposure is an important occupational health issue. Although the exact number of outdoor workers in South Africa is unknown, the large range of outdoor occupations present in the country suggests this subpopulation is sizeable. In addition, there are no solar UV radiation-specific legislation or safety limits for outdoor workers in South Africa. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) exposure limit of 0.3 SEDs (SED = Standard Erythemal Dose, 0.3 SEDs = 30 Jm⁻²) issued in 1999 has been adopted in some countries for occupational exposure (8-hr) to UV radiation for exposure to artificial sources. Thus, an occupational limit does exist for indoor ultraviolet radiation exposure, for example, during arc welding, but there are no occupational limits defined by time or exposure for outdoor occupational exposure and ICNIRP advises that personal discretion is applied. Previous studies done elsewhere have shown that outdoor workers do not make regular use of adequate control strategies, including protective clothing, hats, shade, sunglasses and sunscreen and there may be ethno-racial differences in sunscreen and sunglasses use, as noted among outdoor workers in southern California.

To date, no attempts have been made to empirically measure the personal solar UV radiation exposure or sun protection habits of South African outdoor workers. In 2000, a desktop study comprising a human health risk assessment of solar UV radiation exposure was carried out on four lifestyle scenarios, including an outdoor worker, living in Durban and results indicated that outdoor workers were at high risk of excess sun exposure. While a sample of Durban schoolchildren’s sun exposure has been measured using personal dosimeters, no such study has been carried out among outdoor workers living in South Africa. This knowledge is needed to help guide skin cancer prevention and sun awareness campaigns, and motivate to employers to educate and support sun awareness among their employees. This research used ambient solar UV radiation data to estimate possible outdoor worker exposure among South Africans as a first step towards understanding exposure and sunburn risk patterns by season and skin type at a national level. This level of information is needed to develop a comprehensive strategy to minimise sun-related risks, since the sun cannot

### Table 1. Skin phototype classification with solar UV radiation exposure estimates likely to cause sunburn on un-tanned skin

<table>
<thead>
<tr>
<th>Skin type; Unexposed skin colour; UV radiation sensitivity</th>
<th>Constitutive characteristics</th>
<th>History of sunburn</th>
<th>Continuous UV radiation exposure estimated to elicit sunburn on un-tanned skin (SED*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I White Extremely sensitive</td>
<td>Fair skin, blue or light eyes and freckles</td>
<td>Always burns on minimal exposure</td>
<td>2 - 3 SEDs</td>
</tr>
<tr>
<td>II White Very sensitive</td>
<td>Red or blonde hair, blue, hazel or brown eyes and freckles</td>
<td>Burns very readily, freckles common</td>
<td>2.5 - 3 SEDs</td>
</tr>
<tr>
<td>III White or light brown Moderately sensitive</td>
<td>Brown hair and blue, hazel or brown eyes</td>
<td>May burn on regular exposure with no protection, tans slowly</td>
<td>3 - 5 SEDs</td>
</tr>
<tr>
<td>IV Light brown Relatively tolerant to UVR</td>
<td>Brown hair and dark eyes</td>
<td>Burns rarely, tans rapidly with minimal exposure</td>
<td>4.5 - 6 SEDs</td>
</tr>
<tr>
<td>V Brown Variable</td>
<td>Brown eyes and dark brown or black hair</td>
<td>Despite pigment, may burn easily on exposure</td>
<td>6 - 20 SEDs</td>
</tr>
<tr>
<td>VI Black Relatively insensitive</td>
<td>Brown eyes and dark brown or black hair</td>
<td>Rarely burns, though sunburn is difficult to detect on heavily pigmented skin</td>
<td>6 - 20 SEDs</td>
</tr>
</tbody>
</table>

*SED, Standard Erythemal Dose; 1 SED = 100 Jm⁻².
be controlled in the same way as other workplace exposure hazards. Improved sun awareness and skin cancer prevention education is needed among outdoor workers and their employers. Co-ordinated, evidence-based research programmes are required to abate the public health risks associated with excess solar UV radiation exposure, awareness campaigns and prevention methods.15

MATERIALS AND METHODS

Ambient solar UV radiation data

Solar UV radiation is divided into three electromagnetic bands: UV-C, UV-B and UV-A.4 Most UV-C is absorbed by stratospheric ozone in the atmosphere and only a small portion reaches the Earth’s surface. UV-B and UV-A are more likely to reach the Earth’s surface and pose human health risks. Several factors influence the amount of solar UV radiation received at the Earth’s surface, such as altitude, latitude, aerosols, thickness and distribution of clouds, stratospheric ozone, surface reflection, solar zenith angle and time of day.4 Erythemal or sunburn-causing UV radiation is defined as UV-B irradiance weighted by the action spectrum for sunburn or erythema.16 Exposure to solar UV-B radiation has been associated with the occurrence of sunburn.4 For this reason, solar UV-B radiation was the focus of this research.

The South African Weather Service (SAWS) monitors ambient solar erythemal UV-B (defined as between 290-320 nm) levels at six stations around South Africa, namely Pretoria (25.7° S, 28.2° E), Durban (30.0° S, 31.0° E), Cape Town (33.98° S, 18.6° E), Cape Point (34.35° S, 18.48° E), De Aar (30.7° S, 24.0° E), and Port Elizabeth (33.9° S, 25.5° E) (Figure 1). The main purpose of the solar UV radiation monitoring network is to create and enhance public awareness and provide real-time information about the hazard of personal sun exposure.

The instrument used to measure daily ambient solar UV radiation, from sunrise to sunset, is a UV Biometer (model 501) comprising a Robertson-Berger pattern UV radiation detector, digital recorder and control unit. The erythemal UV-B spectral range closely mimics the McKinley / Diffey Erythema Action Spectrum.16 Logged readings were converted into hourly SED values, the international standard unit for expressing solar UV radiation exposure (defined as 1 SED = 100 Jm⁻²).7 Data for 2006 were applied in this study since this data set was the most complete (8 days missing during December for the Port Elizabeth station) and recent (at the time of carrying out this research) for all six stations. A full investigation of the monitored ambient solar UV radiation levels to explain inter-station differences requires geophysical and atmospheric data, as well as calibration factors, currently unavailable in South Africa. Hence, the focus of this work was on the measured solar UV radiation data recorded at the monitoring stations.

Possible outdoor worker solar UV radiation exposure calculations

No South African personal UV radiation exposure study has determined the solar UV radiation exposure levels among outdoor workers. However, international population studies have done so. In a New Zealand personal UV radiation dosimetry study among outdoor workers, defined as builders, horticulturalists and road workers, monitored results showed that outdoor workers received about 20% of the total daily ambient solar UV radiation levels.9 This percentage was similar to that found in several other studies in Australia 18 and Germany19 and lower than that found in Switzerland.20 Several factors may influence this percentage including type of outdoor work, anatomical attachment site of the personal UV dosimeter, local ambient solar UV radiation and temperature levels, and personal sun protection practices. Previous studies found that outdoor workers received about 10–70%21 of the total daily ambient solar UV radiation depending on the amount of work time spent outdoors; and the anatomical site of measurement may vary this percentage from 11% (on the chest)22 24% on the back22 and 2–17% for the eyes depending on hat use and seasonal variations.23

For this study, potential outdoor worker solar UV radiation exposure was defined as 20% of the measured total daily ambient solar UV radiation levels. The rationale for selecting 20% was a conservative, median estimate of all studies that have considered outdoor worker sun exposure as a percentage of the ambient solar UV radiation exposure, as well as generalised for all anatomical sites. This percentage may be higher or lower for specific outdoor occupation types or different anatomic sites. For example, in a recent study among Italian vineyard workers, for spring months, backs received between 53% and 87% of ambient exposure, and arms between 30% and 60%.24 Possible outdoor worker solar UV radiation exposures were calculated for the six cities or towns where ambient solar UV radiation was monitored.
by SAWS. Seasonal trends in possible solar UV radiation exposure patterns among outdoor workers are described. Summer, autumn, winter and spring were defined by the months of December, January and February; March, April and May; June, July and August; and September, October and November, respectively.

The risk of sunburn, an indication of excess sun exposure and associated in skin cancer aetiology, has been defined by skin type (see Table 1). This was overlaid onto the quantified outdoor worker solar UV radiation exposures to provide an indication of exposure and, subsequently, the health risk of sunburn. By superimposing the minimal amount of solar UV radiation exposure required to elicit sunburn response for different skin types onto the annual variation in outdoor workers’ solar UV radiation exposure, the number of days during one year when an outdoor worker of a particular skin type may be at risk of sunburn was estimated. Since some outdoor workers, such as farmers, work seven days per week, weekdays, weekend days and public holidays were included. No individuals were involved in this study and only hypothetical scenarios were applied.

RESULTS AND DISCUSSION

Ambient solar UV radiation levels
Figure 2 shows the mean and median total daily ambient solar UV radiation levels (SED units) at six monitoring stations in South Africa. The typical pattern of highest levels during summer and lowest levels during winter is evident. Highest total daily ambient levels, ranging between 35.8 SEDs in Port Elizabeth and 70.7 SEDs in De Aar, were recorded during summer months (i.e. December, January and February) for all stations. Total daily ambient levels in De Aar were consistently higher than all other stations, probably because it is a small town in the Northern Cape with little industrial activity and relatively clear skies. Pretoria and Durban, northern sites compared to those situated in the Western Cape and Eastern Cape, experienced relatively high total daily ambient solar UV radiation levels during summer with mean values of 38.8 and 48.2 SEDs, respectively. Wintertime values ranged between 8.9 SEDs at Cape Point and 17.4 SEDs and 18.7 SEDs in Pretoria and De Aar, respectively. Even though Cape Point and Cape Town appear to be relatively closely situated in Figure 1, differences in the ambient solar UV radiation levels, shown in Figure 2, measured at these two sites may be on account of localised and highly variable cloud and aerosol conditions at the respective sites.

Total daily solar UV radiation exposures among outdoor workers
For a national perspective, a worst-case scenario for total daily solar UV radiation exposure among outdoor workers

Continued on page 27
Figure 3. Potential total daily outdoor worker solar UV radiation exposure (SED units, 1 SED = 100 Jm\(^{-2}\)) at (a) De Aar, Cape Point and Port Elizabeth and (b) Pretoria, Durban and Cape Town.
Continued from page 25

was calculated using 20% of the total ambient solar UV radiation levels. The mean (median and range in parentheses) in total daily solar UV radiation exposures (in SED units, 1 SED = 100 Jm⁻²) among outdoor workers during one year for Pretoria, De Aar, Durban, Cape Town, Cape Point and Port Elizabeth were 5.64 (5.37; 2.27-11.33), 6.08 (4.94; 1.90-15.49), 5.53 (5.22; 3.96-11.81), 7.92 (6.84; 3.46-17.15), 5.45 (4.80; 3.74-11.16) and 4.77 (3.97; 1.77-11.62), respectively.

These results compare favourably with the measured personal exposure among outdoor workers in New Zealand (geometric mean total daily UV radiation exposure was 5.32 SEDs for the shoulder bone / lapel anatomic site, worn as a badge) and Australia (median measured exposure was 4.53 SEDs at the lapel site, worn as a badge). In Australia, the International Commission Non-Ionizing Radiation Protection (ICNIRP) exposure limit of 0.3 SEDs (30 Jm⁻²), revised in 2004, was adopted for occupational exposure (8-hr) to UV radiation including exposure to artificial sources and solar UV radiation. Applying this exposure limit, very few potential total daily solar UV radiation exposures among South African workers would comply.

Personal sun exposure is influenced by, among other factors, timing and duration of exposure, type of activity, body position and use of sun protection. Occupational sun exposure may be influenced by working hours, nature of occupation and use of personal protective equipment. Since total daily ambient solar UV radiation levels were applied, these factors cannot be included or considered. Real-time personal exposure monitoring using time-activity diaries, measures of sun protection practices and personal solar UV radiation dosimetry is needed among outdoor workers to validate these findings.

Potential outdoor worker sunburn risk by geographical location, season and skin type

Figures 3a and 3b depict the potential outdoor worker total daily solar UV radiation exposure for De Aar, Cape Point and Post Elizabeth, and Pretoria and Cape Town, respectively. Sunburn risk is overlaid by skin type according to the required solar UV radiation exposure amount needed to cause a sunburn response as defined in Table 1. For an outdoor worker with skin type II (moderately sensitive), continuous exposure of between 2.5 - 3 SEDs may cause a sunburn response, depending on bodily orientation, sun protection etc.

The general pattern in calculated solar UV radiation exposure among outdoor workers is typical of seasonal trends through one year in ambient solar UV radiation levels. An envelope-shape is evident and the scatter below the envelope for each location is usually indicative of cloud effects. There were very few days in a year when sunburn was unlikely to be experienced by an outdoor worker in any location. Outdoor workers are particularly susceptible to the effects of non-melanoma skin cancer and ocular diseases . . .

workers with skin types I and II in all locations were identified as being at risk of sunburn almost all year round. Outdoor workers in De Aar, Pretoria and Durban tended to have higher exposure values compared to Cape Town, Cape Point and Port Elizabeth, the main reason being the impact of geographic latitude on ambient solar UV radiation. In South Africa, solar UV radiation levels are higher closer to the Equator, i.e. at lower latitudes, where the sun is more directly overhead compared to at higher latitudes closer to the poles.

The total number of days during one year that outdoor workers in Pretoria, Durban, De Aar, Cape Town, Cape Point and Port Elizabeth may be at risk of experiencing sunburn is shown in Table 2. As noted earlier, weekend days have not been excluded since some outdoor workers may work 5-, 6- or 7-day weeks depending on the nature of their occupation. This would mean that for outdoor workers working from Monday to Friday, the calculated total number of days when they were at risk of experiencing sunburn may not be a true reflection of their risk because they may not have been at work.

Seasonal differences in the number of days that outdoor workers may be at risk of experiencing sunburn based on their potential total daily solar UV radiation exposures are given in Table 2. Outdoor workers in all locations were at greatest risk of experiencing sunburn during summer and spring months.

Table 2. Total number of days per year and per season that outdoor workers of varying skin types may be at risk of experiencing sunburn from excess solar UV radiation exposure depending on activity and sun protection, using an estimated personal exposure of 20% of the total daily ambient solar UV radiation levels

<table>
<thead>
<tr>
<th>Skin type I</th>
<th>Skin type II</th>
<th>Skin type II</th>
<th>Skin type VI</th>
<th>Skin type V &amp; VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Sum Aut Win Spr</td>
<td>Sum Aut Win Spr</td>
<td>Sum Aut Win Spr</td>
<td>Sum Aut Win Spr</td>
</tr>
<tr>
<td>Pretoria</td>
<td>364 90 92 92 90</td>
<td>346 88 86 82 90</td>
<td>330 87 82 72 89</td>
<td>223 80 48 14 81</td>
</tr>
<tr>
<td>Durban</td>
<td>343 89 84 86 86</td>
<td>327 89 81 73 84</td>
<td>281 88 73 39 81</td>
<td>199 75 50 7 67</td>
</tr>
<tr>
<td>De Aar</td>
<td>341 75 90 85 91</td>
<td>334 75 86 82 91</td>
<td>324 75 83 76 90</td>
<td>149 74 65 21 89</td>
</tr>
<tr>
<td>Port Elizabeth</td>
<td>272 81 76 26 89</td>
<td>250 80 68 18 84</td>
<td>221 80 52 8 81</td>
<td>166 73 32 0 61</td>
</tr>
<tr>
<td>Cape Town</td>
<td>290 90 74 36 90</td>
<td>259 90 65 18 86</td>
<td>237 90 55 7 85</td>
<td>194 88 38 0 68</td>
</tr>
<tr>
<td>Cape Point</td>
<td>278 90 70 30 88</td>
<td>253 90 60 16 87</td>
<td>231 90 50 6 85</td>
<td>191 89 31 0 71</td>
</tr>
</tbody>
</table>

Note: Sum = Summer (Dec, Jan, Feb); Aut = Autumn (Mar, Apr, May); Win = Winter (Jun, Jul, Aug); and Spr = Spring (Sep, Oct, Nov)
however, for almost all seasons, locations and skin types, there was at least one day when sunburn risk was possible. For all locations, except De Aar, outdoor workers of skin types I - IV were also at risk of sunburn during winter months. The melanin content in the skin of outdoor workers with skin types V and VI would provide sufficient sun protection for the relatively lower ambient solar UV radiation levels experienced during winter months, except for the 4 days during winter in De Aar. The likely reason for this high number of sunburn risk days for outdoor workers all year around is duration of their exposure, in this case, having used 20% of the total daily ambient solar UV radiation to estimate outdoor worker exposure.

The timing of exposure is important as solar UV radiation levels follow a diurnal pattern that increases from sunrise to solar noon (i.e. around midday) and then decreases as sunset draws nearer. Between 12h00 to 13h00 when the sun is directly overhead, outdoor workers may seek shade for a lunchtime break; however, their total daily exposure is likely to remain high due to lengthy time periods outdoors either side of midday. The World Health Organization recommends limiting exposure during and / or use of adequate sun protection between 10h00 and 16h00 when ambient solar UV radiation levels are at their highest. Outdoor workers’ tasks may require that they spend time outdoors during this period of the day in which case adequate personal sun protective equipment is required, particularly for individuals with sensitive and moderately sensitive skin types.

CONCLUSION AND RECOMMENDATIONS

Given the relatively high rate of skin cancer and eye-related conditions in South Africa (although substantive recent and available data are sparse), and the World Health Organization’s priority to protect outdoor workers from solar UV radiation, it was deemed important to assess potential outdoor worker sunburn risk patterns for South Africa. In this study, ambient total daily solar UV radiation levels, measured using a nation-wide monitoring network used for the primary objective of raising awareness, were used to estimate the potential total daily solar UV radiation exposure for outdoor workers in South Africa. Limitations of this approach include the use of total daily ambient solar UV radiation levels; applying a generalised percentage of 20% of the total daily ambient solar UV radiation for outdoor worker sun exposure and for a generalised anatomic site; and including weekend days and public holidays in estimations since some outdoor workers may work 5-, 6- or 7-day weeks. The
preferred method for estimating personal sun exposure is using real-time, time-stamped solar UV radiation measurements and self-recorded activity patterns; however, this has not been done in South Africa.

Outdoor workers of all skin types were at risk on at least some days in all seasons (except skin types V and VI during winter, excluding in De Aar) of excess solar UV radiation exposure and sunburn. Further research, in addition to this study’s findings and including information on skin cancer incidence among outdoor workers, is needed to develop comprehensive research, awareness and prevention strategies to minimise risks associated with excess occupational sun exposure.

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LESSONS LEARNED

- Outdoor workers with skin types I, II and III (ranging from extremely to moderately sensitive) were identified as being at greatest risk of sunburn all year-round.
- Personal protective equipment and clothing for outdoor workers, especially for those with skin types I, II and III, should include sun protection, i.e. broad-brimmed hat, long-sleeve shirt and sunscreen.
- The World Health Organization recommends limiting exposure between 10h00 and 16h00 when ambient solar UV radiation levels are at their highest.

REFERENCES