Personal solar ultraviolet radiation exposure of farm workers: seasonal and anatomical differences suggest prevention measures are required

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Abstract

Introduction Farmworkers are at risk of excess exposure to solar ultraviolet radiation (UVR) during their work activities, especially if they work in geographical areas with high ambient solar UVR levels such as in South Africa. Excess exposure to solar UVR may lead to several negative health effects such as certain cataracts and skin cancer. This study evaluated personal solar UVR exposure of a group of farmworkers to determine if they were at risk of related-health problems due to excess solar UVR exposure. **Methods** Polysulphone film (PSF) badges were placed on the shoulder, arm and top of the head of outdoor and indoor farmworkers on a macadamia nut and avocado farm in the Limpopo province for the duration of their daily work shift to evaluate their total daily solar UVR exposure. Sixteen days were assessed for each of the three, high solar UVR seasons, i.e., autumn, spring, and summer. **Results** During autumn, farmworkers' arms received the highest solar UVR exposures (Geometric Mean (GM) = 7.8 SED, where 1 standard erythemal dose (SED) = 100 J/m^2, CI 95% 6.1 - 9.8 SED) while the highest exposures were on the top of the head during spring (GM = 11.6 SED, CI 95% 7.3 - 17.4 SED) and summer (GM = 13.9, CI95% 10.4 - 17.9 SED). Statistically significant differences in solar UVR exposure were found between the body sites during spring and summer but not autumn. **Conclusions** The relatively high daily solar UVR exposure levels of farmworkers suggest this occupational group is at risk of excess solar UVR exposure and preventive measures with awareness information to safeguard health is necessary for employers and employees.

***Keywords**:* agricultural workers, environmental health, ultraviolet radiation occupational exposure, South Africa.

Importance of research

This is the first study to our knowledge to evaluate the personal solar UVR exposure of farmworkers on the African continent. Farmers and farmworkers have been identified as being of high risk of exposure to solar UVR. This is a concern as the ambient UVR levels in many African countries such as South Africa are high. This study quantified the personal exposure of this high-risk occupational group and enables employers to implement appropriate photoprotective measures to safeguard worker health. Summer is considered as the season in which outdoor workers are at the highest risk of exposure to solar UVR, however it may not be possible to assume that their exposure during other seasons such as autumn and spring complies with recommended solar UVR exposure limits. The evaluation of the seasonal personal solar UVR exposure of the outdoor farmworkers in our study can be used to determine if the use of photoprotective measures is needed in not just summer, but also autumn and spring by the workers. The solar UVR received by different body sites while working is influenced by the body's posture. To our knowledge, our study is one of the few studies that investigated solar UVR exposure on different body sites during a range of different work activities found on a farm.

Introduction

Outdoor workers such as farmworkers are at high risk of exposure to levels of solar ultraviolet radiation (UVR) above the recommended exposure limit due to the long periods of time spent in the sun (ICNIRP, 2010). Excess exposure to solar UVR may lead to different skin cancers, development of certain cataracts and systemic effects such as reduced immunity (Ivanov et al, 2017; Bernard *et al*., 2019). Individuals with darker skin may have a higher melanocytic protection against health effects related to solar UVR skin exposure but this natural protection can be overwhelmed by exposure to high levels of solar UVR, although the mechanisms remain unclear (Greinert *et al*., 2015). In addition, they are still vulnerable to the effects related to solar UVR exposure of the eyes (Agbai *et al*., 2014). The link between exposure to solar UVR and skin cancer in individuals with darker skin has been debated with most research finding no link between solar UVR exposure and melanoma. Further epidemiology and laboratory research may be needed (Liu *et al*., 2016).

Prevention of the above-mentioned adverse health effects remains essential in individuals of all skin types. Understanding exposure levels is key, hence several methods have been developed to evaluate the personal exposure of individuals who may be exposed to excess solar UVR (King *et al*., 2015) rather than using ambient solar UVR levels as a proxy for personal exposure given differences in occupational, behavioural and anatomical factors that influence personal solar UVR exposure (Casale *et al*., 2015; King *et al*., 2015). For example, body posture assumed while in the sun may be determined by work demands related to the crop type on a farm, e.g., bending low or reaching high up (Salas *et al*., 2005; Nardini *et al*., 2014). In an occupational environment, the type of work influences the body posture and the length of time spent in the sun making it necessary to assess the personal solar UVR exposure of different types of occupations, including farm work (Schmalwieser *et al*., 2010).

Research studies conducted in several Europe countries, i.e., Austria, Denmark, Poland, Spain and Italy (Schmalwieser *et al*., 2010; Siani *et al*, 2011; Bodekær *et al*., 2015) investigated personal solar UVR exposure of agricultural workers (including farmers, farmworkers and vineyard workers etc.) using personal dosimetry. Although some of the studies used different measurement methods and included different types of agricultural activities, all of them found that agricultural workers' exposure exceeded the exposure limit recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) and/or the International Commission on Non-Ionizing Radiation Protection (ICNIRP) (ICNIRP, 2010; Schmalwieser *et al*., 2010; Siani *et al*, 2011; Bodekær *et al*., 2015; ACGIH, 2020).

A guideline occupational exposure limit (OEL) of 30 J/m^2 ~~or 0.3 SED~~ for eight hours is recommended by the ACGIH and the ICNIRP using ~~the ACGIH~~ an envelope action spectrum for exposure of the eyes and the skin to UVR (ICNIRP, 2010). The action spectrum refers to the relationship between the wavelength of the UVR and its photobiological effect (Geiss *et al*., 2003). Considering acute skin effects from solar exposure, the ICNIRP guideline OEL for maximum human biologically efficient radiant exposure of the skin and eyes to UVR of 30 J/m^2 is equivalent to nearly 1.0 - 1.3 SED. This equates to approximately 50% of a minimum erythemal dose (MED) for fair skin (ICNIRP, 2010), where the level of exposure is weighted against the erythemal effectiveness curve (CIE, 1998, ICNIRP, 2010).

There is a lack of knowledge regarding the solar UVR exposure of outdoor workers and specifically farmworkers on the African continent including in South Africa (Lucas *et al*., 2016). To our knowledge, no such study to assess personal solar UVR of farmworkers has been conducted in Africa. This lack of knowledge is of concern as agriculture is a major occupational sector in both South Africa and the rest of Africa (STATSSA, 2020; Cristiaensen and Demery, 2018). Excess solar UVR exposure of individuals engaging in agricultural activities may lead to increased occurrence of associated negative health effects which will place heightened pressure on already burdened health care systems (Glanz *et al*., 2007). South African skin cancer prevalence rates vary by population group and are highest among people with light skin (Kellet *et al*., 2014). The 2016 National Cancer Registry report indicated that 31.9% of cancers diagnosed in White females and 35.4% of those diagnosed in White males were identified as basal cell carcinoma (BCC) while the same cancer constituted only 1.6% of all cancers diagnosed in Black females and 2.4% in Black males (NCR, 2020). Cortical cataracts are known to be partly cause by excess solar UVR exposure (Lucas *et al*., 2016). Studies have determined the prevalence of cataracts in South Africa in both rural and urban settings for example a prevalence of 44.0% was established in selected rural communities in the Limpopo Province while a prevalence of 27.0% was found in Cape Town (Cockburn *et al*., 2012; Khoza *et al*., 2020).

Therefore, the aim of this study was to evaluate the personal solar UVR exposure and to determine risk of excess solar UVR exposure of farm workers on a macadamia nut and avocado farm in the Limpopo Province of South Africa. Additionally, we investigated the differences between the solar UVR measured on three different body sites during different seasons and compared the personal solar UVR exposure of mainly outdoor and indoor farmworkers to inform prevention and awareness campaigns for occupational sun exposure protection.

Methods

Study setting and participants

The study was conducted on a commercial macadamia and avocado farm in the Soutpansberg mountain range of the Limpopo province in South Africa (latitude: 22.58°S 29.7°E, altitude 1216 - 1392 m). Measurements were taken during three seasons, namely autumn (26 March 2018 to 18 May 2018), spring (05 November 2018 to 28 November 2018) and summer (04 February 2019 to 12 February 2019) for 16 days per season. Measurements were only taken in these three seasons and not in winter because it was anticipated the highest solar UVR would occur in these seasons and the lowest solar UVR in winter. Given the targeted approach of the study, all farmworkers on the farm were invited to participate in the study. Although the focus was on outdoor farmworkers, all farmworkers including those workers who mainly worked indoors were invited to participate in the study. Farmworkers who worked four hours or more of their shift outside, for at least 30 minutes at a time, were defined as outdoor farmworkers and workers who worked at least seven hours of their shift inside were defined as indoor farmworkers. Efforts were made to include outdoor farmworkers who performed a variety of different work activities including harvesting macadamia nuts and watering trees. Research ethics approval was granted by the North-West University Health Research Ethics Committee (NWU-00101-17-A1).

Polysulphone badge dosimetry

Polysulphone film (PSF) badges are small squares of film framed with cardboard borders. The optical absorbance of PSF changes when exposed to solar UVR in a manner that is proportional to the erythemal effective exposure dose (Peters *et al*., 2019). The specific change in absorbance of the PSF badges was determined using a spectrophotometer (DLAB SP-UV1000) at a wavelength of 330 nm. A calibration curve was created by calibrating the response of the PSF badges against the sun as source of UVR. A previously determined 5% correction factor (Geiss *et al*., 2003) was subtracted from the absorbance to counteract the effect of the dark reaction since due to logistical reasons, the PSF badges could not be analysed within 24 hours after exposure. A set of PSF badges were exposed to solar UVR and the change in absorbance for each was compared to solar UVR measured by a broadband radiometer located at the South African Weather Service in Pretoria, South Africa. The calibration curve that was created, was used to convert the change in absorbance in the PSF used to measure solar UVR exposure during data collection to J/m^2 (Peters *et al*., 2019). The solar UVR levels were then converted to SED, which is the standardized, biologically-weighted unit for the erythemal action spectrum with 100 J/m^2 equal to 1 SED (EN14255-3, 2018).

A new PSF badge was attached with the use of surgical tape on the shoulder, arm and top of the hat of participants for the duration of their shift each measurement day. Farmworkers wore the PSF badges for 8 hours each day. Daily ambient solar UVR were measured by placing two PSF badges in an unshaded area on a horizontal surface on the farm for the same time as badges were placed on the participants.

Data analysis

Descriptive statistics were used to describe the daily ambient solar UVR by season as well as the personal solar UVR exposures of the three body sites during different farm work activities on study participants. The one-way ANOVA test was used to establish differences between the mean ambient solar UVR levels of the three seasons. The solar UVR levels on the different body sites of both indoor and outdoor workers were not normally distributed and were therefore log-transformed prior to statistical analysis. The repeated measure ANOVA with a Greenhouse-Geisser correction and with the Bonferroni post-hoc correction was used to compare the means of the solar UVR found on the different body sites during one season for both outdoor and indoor worker groups. The independent t-test was used to compare the solar UVR measured on each body site between outdoor and indoor workers. The correlations between the solar UVR exposure of the different body sites within both outdoor and indoor workers were established using Pearson correlations. All statistical analyses were conducted using

IBM SPSS statistical software (version 25) with statistical significance indicated by p ≤ 0.05.

Results

Sample description

A total of 73 farmworkers consented to take part in the study of which 61 were outdoor farm workers and 12 were indoor farmworkers. The numbers differed by season with 32 outdoor workers and three indoor workers included during autumn, and 19 outdoor workers and four indoor works were included during spring. During summer, 26 outdoor workers and five indoor workers were assessed.

Daily ambient solar UVR

The highest mean ambient solar UVR levels were measured during summer (35.0 ± 15.0 SED) which was higher, but not statistically different from that of spring (34.4 ± 19.49 SED) and autumn (18.9 ± 1.3) (F=2.0, p=0.2) (Figure 1). During the data collection periods, various weather conditions were noted including rain, clear skies, partly cloudy conditions, mist and fog in the region where the study site is located.

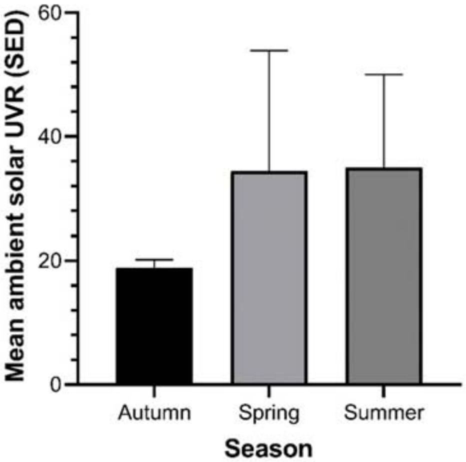

Figure 1: The mean ambient solar UVR levels (SED, 1 SED = 100 J/m^2) measured during the three seasons.

Personal solar UVR exposure by anatomical site and season

As measured on the arm, while the lowest mean exposure was measured on the shoulder. Likewise, the arm also received the highest mean solar UVR exposure in the indoor worker group. The mean solar UVR exposure on the arm (p=0.04) and top of the head (p=0.05) differed significantly between outdoor and indoor workers.

During spring, the top of the head received the highest mean solar UVR exposure in the outdoor worker group while the arm received the lowest exposure (Table 1). When comparing the body sites, they differed statistically significantly from each other in the outdoor workers (p≤0.001). Statistically significant differences were found between the solar UVR exposure on the shoulder and arm (p≤0.01) and the arm and the top of the head (p≤0.001) of the outdoor workers. The arm received the highest mean solar UVR exposure in indoor workers. The mean solar UVR exposure on all three body sites differed significantly between outdoor and indoor workers, namely shoulder (p≤0.001), arm (p≤0.001) and top of the head (p≤0.001). Strong significant positive correlations were found in the outdoor workers between the solar UVR measured on the shoulder and both the arm (p=0.88, p≤0.001) and top of the head (p=0.84, p≤0.001), as well as between the arm and top of the head (p=0.88, p≤0.001).

The top of the head received the highest mean solar UVR exposure in outdoor workers during summer while the arm received the lowest mean solar UVR exposure. The solar UVR on the body sites of the outdoor workers were statistically significantly different from each other with differences found between the arm and the shoulder (p≤0.01) as well as between the arm and the top of the head (p≤0.01). In the indoor worker group, the highest mean solar UVR exposure was measured on the top of the head.

The mean solar UVR exposure on the shoulder (p≤0.001) and top of the head (p=0.04) also differed significantly between outdoor and indoor workers. Significant strong positive correlations were found between the solar UVR exposure measured on the shoulder of outdoor workers and both the arm (p=0.69, p≤0.001) and top of the head (p=0.62, p≤0.01), as well as between solar UVR on the arm and top of the head (p=0.47, p≤0.01).

Personal solar UVR as a percentage of ambient solar UVR

The mean percentage of ambient solar UVR that was measured on the anatomical sites of the farmworkers during the three seasons is illustrated in Table 2. The body site of outdoor workers where the highest mean percentage of the ambient solar UVR was measured during all three seasons was the top of the head during spring while the lowest mean percentage on the arm, also during spring. The highest percentage of ambient solar UVR on the body sites of indoor workers was measured during autumn on the arm, and the lowest measured on the top of the head during spring.

Table 1: Personal solar UVR exposures of outdoor and indoor farm workers by season and body sites.

Body site			**Autumn**		**Spring**		**Summer**	
			Outdoor workers	**Indoor workers**	**Outdoor workers**	**Indoor workers**	**Outdoor workers**	**Indoor workers**
Shoulder	**n**		35	3	27	7	30	5
	Daily solar UVR exposure (SED)	**Mean**	7.5	3.1	8.6$^{\#a}$	0.2$^{\#}$	12.3^^{c}	1.9^
		95% CI	5.4 - 9.6	0.6 - 10.2	5.1 - 13.5	0.0 - 1.2	9.0 -16.4	0.7 - 4.8
	% > ICNIRP OEL		97.5	50.0	89.3	28.6	100.0	80.0
Arm	**n**		35	3	27	7	32	5
	Daily solar UVR exposure (SED)	**Mean**	7.8*	3.2*	4.9$^{\#\#,a,b}$	0.3$^{\#\#}$	9.1^{,c,d}	1.9
		95% CI	6.1 - 9.8	1.5 - 11.2	2.7 - 8.7	0.0 - 1.2	6.9 - 11.6	0.7 - 6.2
	% > ICNIRP OEL		97.7	100.0	81.5	14.4	100.0	60.0
Top of head	**n**		35	3	27	7	30	5
	Daily top of head solar UVR exposure (SED)	**Mean**	7.7**	2.2**	11.6$^{\#\#\#,b}$	0.2$^{\#\#\#}$	13.9^^^{,d}	2.6^^
		95% CI	4.5 - 11.6	0.6 - 5.9	7.2 - 17.4	0.0 - 1.4	10.4 - 17.9	0.8 - 6.6
	% > ICNIRP OEL		92.3	50.0	92.6	42.9	96.7	80.0

Notes. n- Number of solar UVR samples, Mean=Geometric mean, 95% CI – Confidence interval, $^{*,\#,}$ ^ indicate statistically significant differences between solar UVR exposure of outdoor and indoor workers (independent t-tests), $^{a\text{-}d}$ indicates statistically significant differences between solar UVR exposure on body sites in a worker group (ANOVA with a Greenhouse-Geisser correction and with the Bonferroni post-hoc correction).

Table 2: Percentage of ambient solar UVR measured on the body sites of outdoor and indoor farmworkers.

Body site		**Autumn**		**Spring**		**Summer**	
		Outdoor workers	**Indoor workers**	**Outdoor workers**	**Indoor workers**	**Outdoor workers**	**Indoor workers**
Shoulder	n	35	3	27	7	30	5
	Mean %	38.8	15.9	$33.2^{\#a}$	$1.8^{\#}$	$37.0^{\wedge c}$	$6.4^{\wedge}$
	95% CI	28.1 - 51.5	2.9 - 52.2	24.8 - 44.2	0.3 - 8.3	27.1 - 48.9	2.2 - 20.4
Arm	n	35	3	27	7	32	5
	Mean %	40.8^{*}	16.2^{*}	$19.1^{,a,b}$	3.8	27.4^{cd}	6.3
	95% CI	32.7 - 501.4	7.8 - 57.2	12.5 - 27.7	0.9 - 16.6	19.7 - 37.0	1.9 - 22.4
Top of head	n	35	4	27	7	30	5
	Mean %	35.4	11.2	$45.1^{\#\#,b}$	$1.7^{\#\#}$	41.5^{d}	8.4
	95% CI	16.2 - 57.4	3.1 - 30.6	35.0 - 57.2	1.9 - 10.3	31.0 - 53.5	2.6 - 29.7

Notes. n- Number of solar UVR samples, Mean = Geometric mean, 95% CI – Confidence interval, $^{*,\#,\wedge}$ indicate statistically significant differences between solar UVR exposure of outdoor and indoor workers (independent t-tests), $^{a\text{-}d}$ indicates statistically significant differences between solar UVR exposure on body sites in a worker group (ANOVA with a Greenhouse-Geisser correction and with the Bonferroni post hoc correction)

During both spring and summer, statistically significant differences in the mean percentage of ambient solar UVR were found between the shoulder and arm (spring: p≤0.01; summer: p≤0.01) and between the arm and the top of the head (spring: p≤0.00; summer: p≤0.01) of outdoor workers. When comparing the mean percentage of the solar UVR measured on the body sites between outdoor and indoor workers, a statistically significant difference was only found on the arm (p=0.04) during autumn. Statistically significant differences were found on all two body sites between outdoor and indoor workers during spring, namely the shoulder (p≤0.001) and top of head (p≤0.001). Significant differences were also found in summer when comparing the shoulder (p=0.04).

Personal solar UVR exposure by work activities

Both outdoor and indoor farmworkers carried out a variety of work activities during their workday for autumn (Figure 2), spring (Figure 3) and summer (Figure 4). Although some work activities stayed the same across all three seasons (such as the activities of the macadamia nut factory, tending seedlings in the nursery and providing security at the gates) there were some work activities that depended on the season. For example, tree branches were broken down using a chipper only during autumn, harvesting macadamia nuts by picking them up from the ground only occurred during summer, while the sorting of avocados in the avocado warehouse occurred during autumn and summer. This variation in work activities was mostly found in the work of outdoor workers which also varied from day to day if they were general workers.

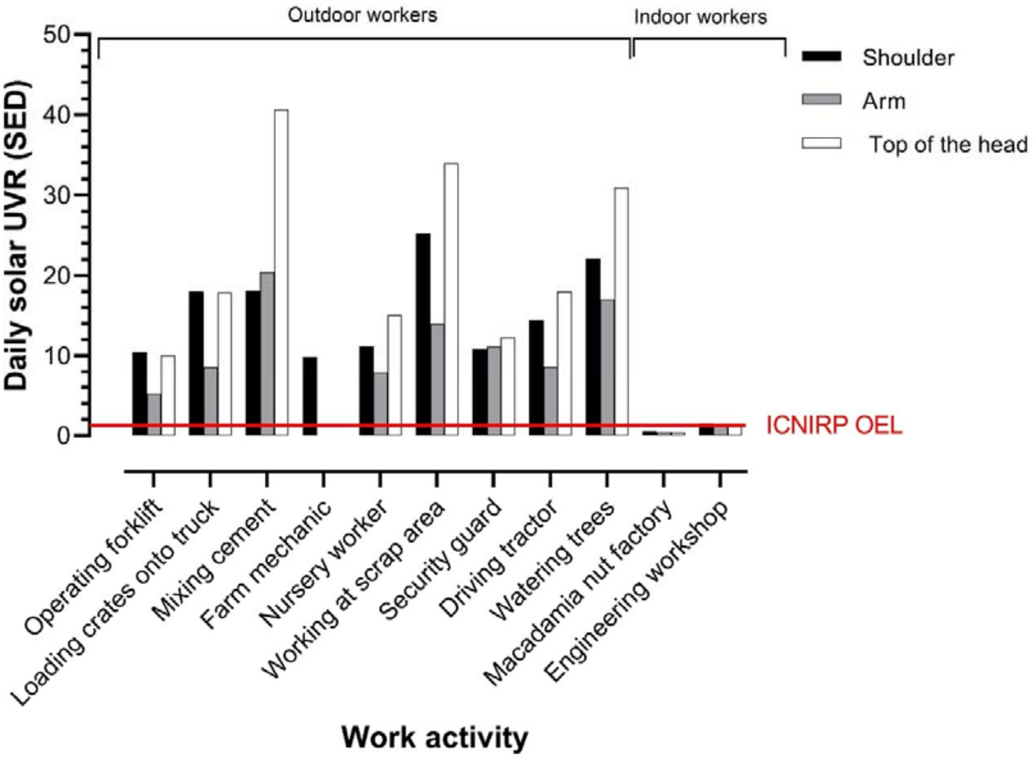

Figure 2: Mean solar UVR exposure on body sites according to work activity in autumn. The ICNIRP OEL is shown by a red line.

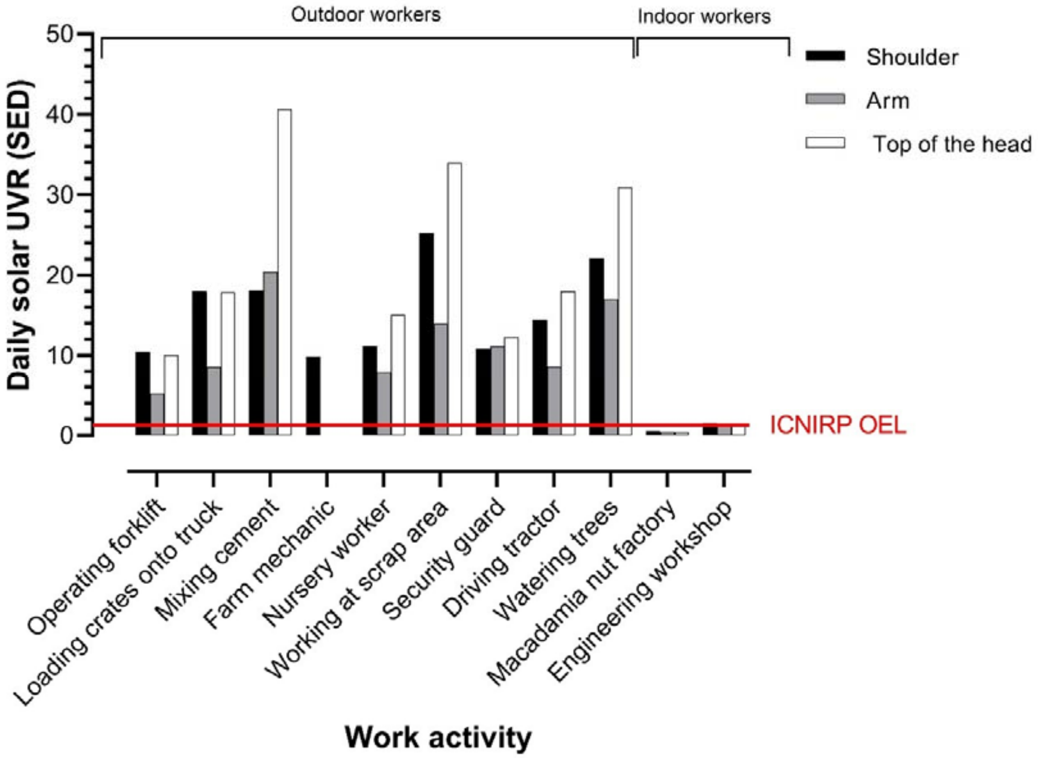

Figure 3: Mean solar UVR exposure on body sites according to work activity in spring. The ICNIRP OEL is shown by a red line.

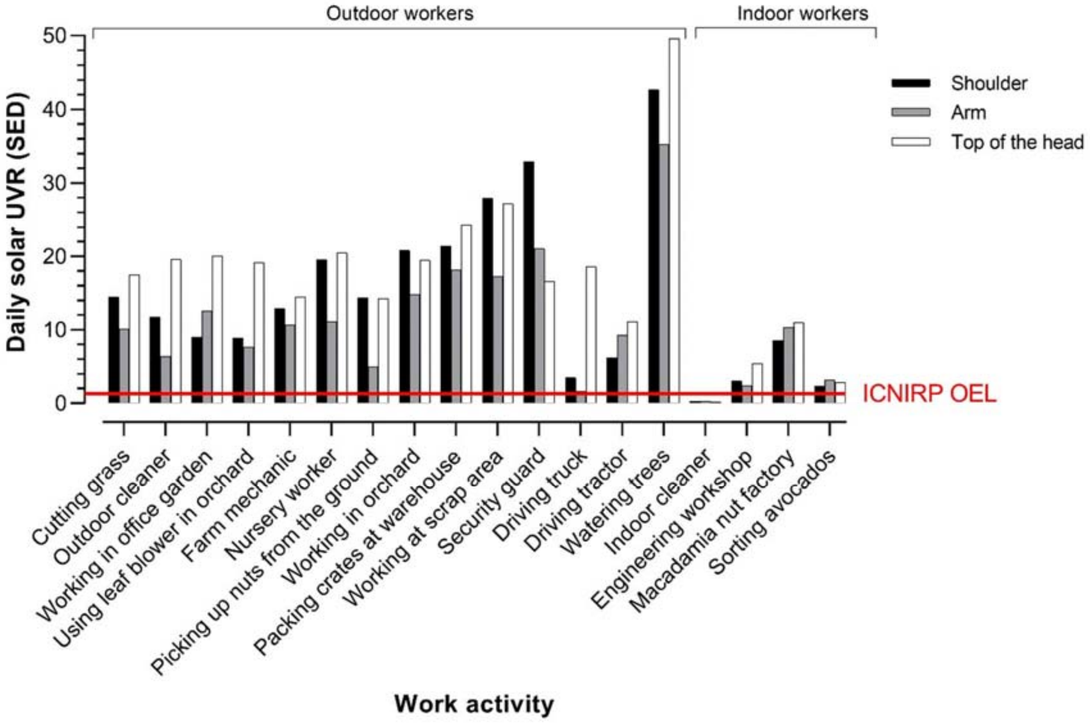

Figure 4: Mean solar UVR exposure on body sites according to work activity in summer. The ICNIRP OEL is shown by a red line.

The type of work done by outdoor workers also included working in both mature and young orchards, carrying out activities such as picking up macadamia nuts from the ground during harvest, watering saplings and operating a tractor. An indoor worker working in the macadamia nut factory would, for example, carry out the same activities each day to process the nuts.

A few farmworkers switched between outdoor and indoor work activities. Their work activities would vary according to the work needs on the day such as cutting grass one day in the orchards and sorting avocados the next day in a warehouse. Hence, the differentiation between outdoor and indoor workers was not always clear-cut, and this is discussed in the limitations.

Discussion

There have only been two studies conducted in South Africa that evaluated occupational personal solar UVR exposure: one among outdoor parking area security staff (Nkogatse *et al*., 2019) and another of a school groundskeeper (Makgabutlane and Wright, 2015). This was the first known study to establish the personal solar UVR exposure of farmworkers in South Africa and goes beyond the earlier work by considering differences in body site and season.

In this study, the arm (in autumn) and the top of the head (in spring and summer) of outdoor workers received the highest mean solar UVR and percentage of solar UVR. These findings differ from studies that focused on cyclists and municipal outdoor workers who found that the top of the head or vertex were exposed to the highest level of solar UVR because it is horizontally orientated and, therefore, most directly facing the sun especially at azimuth (Kimlin *et al*., 2006; Peters *et al*., 2019). Farmworkers engage in various postures depending on the work activity which may have resulted in another body site moving to a more horizontal orientation while the top of the head was positioned at an angle that would not receive as much solar UVR as when the worker was standing upright. The arm received some of the lowest exposure levels, possibly due to having been shaded by other anatomical structures such as the torso during work activities outdoors. The reason that there were no significant differences found between the shoulder and top of the head may be that both sites are horizontally orientated and located relatively close to each other.

Among indoor workers, the arm received higher exposure levels likely due to passing an entrance that would allow solar UVR to enter the indoor work environment. Observations were made that indoor workers moved to outside areas during their break times or when fetching items from either the outside or other buildings before going back to their indoor workplace. Break times were also mostly spent in the shade provided by a canopied area. It was observed that once or twice per season, indoor workers were instructed to carry out outdoor work activities for less than two hours such as loading bags of macadamia nutshells or boxes of avocados onto customers' trucks resulting in some indoor workers being exposed to higher levels of solar UVR than others.

The lack of differences between the body sites of the indoor workers may be due to the short periods of time spent outside and exposed to solar UVR. The effect of this difference in the amount of time spent outside in the sun can also be seen in the significant differences found when comparing the solar UVR exposure of most of the body sites between outdoor and indoor workers.

Although direct comparison is difficult because of differences in the body sites used in different studies, the mean solar UVR exposure measured on the arm of outdoor farm workers in this study during summer was more than five times the levels measured on the wrist of Polish, Austrian and Danish farmers, which ranged from 1.4 SED to 1.7 SED and almost 50% higher than New Zealand horticultural workers (Hammond *et al*., 2009; Bodekær *et al*., 2015). Conversely, the mean solar UVR measured on the arm of the outdoor workers in our study during spring was almost 10 SED lower than the median solar UVR that was measured on the arm of vineyard workers in Italy during the same season (Siani *et al*., 2011). However, the solar UVR measured on the arm of this study's outdoor workers in summer was almost twice the solar UVR measured on the same body site of the Italian vineyard workers during the same season. The higher exposure of the South African farmworkers when compared to most of these farmers and horticultural workers may be due to the higher ambient solar UVR levels in South Africa, and especially the study area, related to latitude and altitude. The Soutpansberg mountain range, where the farm is located, is just north of the Tropic of Capricorn which is closer to the equator than the mentioned European countries or New Zealand (Hammond *et al*., 2009) leading to higher ambient solar UVR levels. In 2004, the average daily ambient solar UVR levels in South African was determined by the World Health Organization (WHO) to be 41.11 SED, while the ambient solar UVR level for Austria and New Zealand during the same year was 18.88 SED and 24.87 SED, respectively (WHO, 2019).

The personal mean solar UVR exposure on the arms of outdoor farmworkers in our study during summer was more than 15 times that which was measured on the arms of South African outdoor parking area security staff which was only 0.29 SED (Nkogatse *et al*., 2019). The reason for the large difference may be the difference in activities carried out by the two jobs such as the relatively stationary position of the parking area security staff when compared to the farm workers who generally move frequently while working and differences in the amount of solar UVR reflected in the two types of work areas. There may also have been more shading structures in the parking area that shielded the parking area security staff from direct solar UVR exposure than in the open areas of the farm.

The differences found between the solar UVR exposure of outdoor and indoor farm workers during autumn are comparable a group of Danish outdoor workers who were exposed to approximately four times higher solar UVR than Danish indoor workers (Grandahl *et al*., 2018). The higher differences in spring and summer may be linked to the higher ambient solar UVR outside which increased the solar UVR exposure of the outdoor workers but the indoor environments and solar UVR exposure of indoor workers stayed relatively the same across seasons.

Although the percentage of solar UVR exposures that exceeded the ICNIRP OEL of 1.3 SED varied between the body sites as well as over the three seasons, more than 80% of outdoor workers received solar UVR exposure that exceeded the ICNIRP OEL on all body sites during all three seasons. The percentage of solar UVR exposures that exceeded the ICNIRP OEL varied noticeably among the indoor workers between the different body sites and across seasons which may be in part due to the small sample sizes in the indoor worker group. Similar percentages were found on the back and arms of Italian vineyard workers (Siani et al., 2011) and Italian ski instructors (Siani et al., 2008). However, other studies found much lower percentages, e.g., 41% on the hardhats of Canadian construction workers (16). However, the ICNIRP has indicated that the use of this exposure limit to determine the risk posed by exposure to solar UVR is problematic in determining the adequate dose for both skin and eyes (ICNIRP, 2010). and it has been criticized as being too strict for populations with more deeply-pigmented skin as it does not factor in the individual's baseline genetic photoprotection (Milon et al., 2007). A study that evaluated the skin colour of the same farmworker group who took part in this study found that the skin colour of 48% of the Black African farm workers could be objectively classified as Type VI (Linde et al., 2020). The exposure to solar UVR at levels that exceed the ICNIRP OEL may not ultimately result in skin cancer in most of the farm workers who participated in this study due to their genetic photoprotection. However, increased pigmentation of the skin does not protect against the effects of excessive solar UVR exposure on the eyes (Agbai et al., 2014), and immunosuppression (Fajuyigbe and Young, 2016) which may still indicate a health risk linked to the exposure of this population to solar UVR that exceeds the ICNIRP OEL.

The percentages of ambient solar UVR that farmworkers on the macadamia and avocado farm were exposed to on the three body sites over the three seasons were higher than most solar UVR exposures reported in other studies. For example, the percentages of ambient solar UVR that farmers' exposure on the wrist in Denmark, Poland, Austria, and Spain were less than 10% in each case while the faces of Austrian farmers were exposed to 12% (Schmalwieser *et al*., 2010; Bodekær *et al*., 2015). The percentage of ambient solar UVR measured on the wrists of New Zealand horticultures during summer, which was 24%, was also lower than the percentage of solar UVR measured on the arm during summer in our study (Hammond *et al*., 2009). The only instances where the percentages were higher than those found in our study, were the 72% and 100% measured on the back of Italian vineyard workers during summer and autumn, respectively, as well as 67% of the ambient measured on the arm in autumn (Siani *et al*., 2011). A school groundskeeper in Pretoria, South Africa was exposed to a comparable percentage of the ambient namely 84% (Makgabutlane and Wright, 2015) which may indicate that activities related to agriculture / horticulture and geographical location has an influence on solar UVR exposure.

The pattern of solar UVR exposure on the different body sites of outworkers varied when engaging in different work activities. The characteristics of the area where the work activity was performed also influenced the level of solar UVR received by the different body sites. This is illustrated by the difference in solar UVR exposure of outdoor farm workers working in the established orchards and those watering saplings in the young orchards. The solar UVR measured on the body sites of the workers in the young orchards were at least 10 SED higher than the level measured on all the body sites of workers working in the established orchards where the trees were larger and had more foliage. This effect of foliage on solar UVR exposure was also found by Siani *et al*. (2011) in Italian vineyards where higher solar UVR exposures during spring than summer which were attributed by the authors to a seasonal decrease in foliage in the vineyard during spring which resulted in higher levels of solar UVR reaching the workers.

Study limitations

We evaluated the solar UVR exposure of different body sites on farm workers in Africa to determine which site received the highest solar UVR exposure during different seasons. Although efforts were made to analyse one PSF badge from each body site for each participant, some PSF badges were lost during the data collection while the analyses of some badges could not take place due to contamination. Six badges could not be used due to dust on the film interfering with the accurate measurement of UVR absorbance. This study was carried out on one large macadamia nut and avocado farm in one province and hence findings may not be readily extrapolated to determine the solar UVR exposure of farm workers in other provinces or on other type of farms due to the effects on personal solar UVR exposure, e.g., geographical location influencing altitude and latitude and behavioural differences in work activities. Further research regarding the personal solar UVR of different types of farm workers in different regions of the country and continent is needed. The small number of indoor workers made some comparisons uncertain. The higher-than-normal solar UVR exposure experienced by one or two indoor workers may have had a bigger effect than would have been found if the sample size had been larger. A larger number of indoor farm workers should be included in further studies to identify a more detailed pattern of their solar UVR exposure. The PSF badges were unable to provide the hourly solar UVR exposure of a farm worker which would provide the changing diurnal pattern of exposure when solar UVR exposures occur. Electronic dosimetry would provide this information. An uncertainty factor of 7% to 10% when using PSF badges has also been reported as well as saturation of the badges due to exposure to high levels of solar UVR (Vernez *et al*., 2015; Diffey, 2020). Random errors that may prevent reproducibility of results have also been identified such as a variation of 1.4% in the solar UVR measured by PSF badges from the same batch (CEN, 2008).

Conclusions

The exposure of the majority outdoor farmworkers to solar UVR on the shoulder, arm and top of the head were higher than what was found in by researchers in other countries. As is the case with several other outdoor occupations, farmworkers are unable to move their work activities to areas with more shade thus preventing workers' ability to decrease their solar UVR exposure. Appropriate alternative photoprotective measures such as protective clothing should be implemented by employers to protect the health of these outdoor workers. An appropriate OEL to protect workers from exposure to harmful levels of solar UVR is needed.

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