

# Exposure of car guards to solar ultraviolet radiation during summer and winter

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***“THE STARTING POINT OF ALL ACHIEVEMENT IS DESIRE” – NAPOLEON HILL***

***“THE FUTURE BELONGS TO THOSE WHO BELIEVE IN THE BEAUTY OF THEIR  
DREAMS” - ELEANOR ROOSEVELT***

## PREFACE

The work presented in this mini dissertation are referenced according to and follows the guidelines of the journal Annals of Work Exposures and Health which are presented in Chapter 3. The language style used in this mini dissertation was British English.

This mini dissertation contains the following:

- **Chapter 1:** Introductory chapter with background and problem statement, aim and objectives as well as hypotheses.
- **Chapter 2:** Literature review focusing on an in-depth understanding regarding factors influencing solar UVR exposure, the effects thereof, methods of measurement and exposure limits.
- **Chapter 3:** Article on car guard exposure to solar UVR during summer and winter with introduction to solar UVR exposure, study protocol, results, discussion and conclusion.
- **Chapter 4:** Concluding chapter with final conclusions, hypotheses, limitations, recommendations and suggestions for future studies.

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## AUTHORS CONTRIBUTIONS

| NAME             | CONTRIBUTION                                                                                                                                                                                                   |
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The following is a statement from the supervisors confirming everyone's role in the study:

*I declare that I have approved the article and that my role in the study as indicated above is representative of my actual role. I hereby give consent that it may be published as part of Ameera Suliman Hadjee's MHSc. (Occupational Hygiene) mini dissertation.*



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## ABSTRACT

**Introduction:** Outdoor workers such as car guards are at an increased risk of excessive exposure to solar UVR due to long hours working in the absence of a shade structure and personal protective equipment. Cumulative exposure increases the risk of developing adverse health effects such as skin cancer, a Group 1 carcinogen, caused by the sun. The aim of this study was to quantify personal solar ultraviolet radiation exposure of car guards during summer and winter.

**Methods:** Car guards' upper arm exposure to solar UVR was measured at the shopping centre for 10 days during summer (20 February 2019 – 05 March 2019) and winter (22 July 2019 – 02 August 2019) respectively by means of Genesis-UV personal electronic dosimeters. The Genesis-UV dosimeter was placed on the upper arm of the participant using an adjustable strap. Results from these measurements were used to estimate solar UVR exposure on various anatomical areas. In addition, hand-held UV monitors were used to determine the levels of ambient solar UVR reaching a flat, horizontal surface and heat stress levels were also determined during the sampling period by means of the QUESTemp<sup>o</sup>32/34. The QUESTemp<sup>o</sup>32/34 was used to evaluate environmental conditions such as temperature and relative humidity influencing the intensity of solar UVR received by workers.

**Results:** The average exposure of car guards to solar UVR was 11.50 SED during summer and 5.47 SED during winter. Exposure as a percentage of ambient UVR during summer was 30.79%, whilst that of winter was 26.61%. The exposure of car guards on the upper arm was below that of other anatomical areas, even though values were in excess of the threshold limit value (TLV). Heat stress measurements obtained during summer indicated a WBGT<sub>o</sub> ranging between 22.60 – 30.94, and that of winter ranged between 8.32 – 20.32.

**Conclusion:** The high exposure of car guards to solar UVR is a concern because while being independent contractors, it is difficult for them to implement the necessary protective measures. The security industry together with companies manufacturing sunscreens and protective clothing (sun hats and long-sleeved shirts) should form a collaboration with each other promoting the effective use of protective measures among car guards.

**Keywords:** Solar ultraviolet radiation, personal exposure, car guards, summer, winter, heat stress, electronic dosimeters and QUESTemp<sup>o</sup>32/34.

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## LIST OF ABBREVIATIONS

|                |                                                                          |
|----------------|--------------------------------------------------------------------------|
| ACGIH          | American Conference of Governmental Industrial Hygienists                |
| BCC            | Basal cell carcinoma                                                     |
| C-drive        | Computer hard drive                                                      |
| CIE            | Commission Internationale de l'Eclairage                                 |
| DB             | Dry bulb                                                                 |
| DE             | Daily exposure                                                           |
| DGUV           | Deutsche Gesetzliche Unfallversicherung                                  |
| DNA            | Deoxyribonucleic acid                                                    |
| EAS            | Erythema action spectrum                                                 |
| EPA            | Exposure as a percentage of ambient UVR                                  |
| GENESIS        | Generation and Extraction System for Individual Exposure                 |
| HI             | Heat index                                                               |
| HREC           | Human research ethics committee                                          |
| i.e.           | That is                                                                  |
| ICNIRP         | International Commission on Non-Ionizing Radiation Protection            |
| IFA            | Institut fuer Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherun |
| NMSC           | Non-melanoma skin cancer                                                 |
| O <sub>3</sub> | Ozone                                                                    |
| OEL            | Occupational exposure limit                                              |
| OHHRI          | Occupational Hygiene and Health Research Initiative                      |
| PSF            | Polysulfone film                                                         |

|              |                                     |
|--------------|-------------------------------------|
| RH           | Relative humidity                   |
| ROS          | Reactive oxygen species             |
| SCC          | Squamous cell carcinoma             |
| SD           | Standard deviation                  |
| SPF          | Sun protection factor               |
| SZA          | Solar zenith angle                  |
| $T_{db}$     | Dry bulb temperature                |
| TDE          | Total daily exposure                |
| $T_g$        | Globe temperature                   |
| TLV          | Threshold limit value               |
| $T_{nwb}$    | Natural wet bulb temperature        |
| TWA          | Time-weighted average               |
| UV           | Ultraviolet                         |
| UVA          | Ultraviolet A                       |
| UVB          | Ultraviolet B                       |
| UVC          | Ultraviolet C                       |
| UVI          | Ultraviolet index                   |
| UVR          | Ultraviolet radiation               |
| WB           | Wet bulb                            |
| WBGT         | Wet bulb globe temperature          |
| $WBGT_{ave}$ | Average wet bulb globe temperature  |
| $WBGT_i$     | Wet bulb globe temperature indoors  |
| $WBGT_o$     | Wet bulb globe temperature outdoors |

WHO            World Health Organization

## **STANDARD UNITS**

|                    |                                  |
|--------------------|----------------------------------|
| am                 | ante meridian                    |
| cm                 | centimetres                      |
| g                  | grams                            |
| J/m <sup>2</sup>   | Joules per metre squared         |
| m                  | metre                            |
| MED                | Minimal erythema dose            |
| mV/cm <sup>2</sup> | millivolt per centimetre squared |
| nm                 | nanometres                       |
| pm                 | post meridian                    |
| SED                | Standard erythema dose           |
| W/m <sup>2</sup>   | Watt per metre squared           |
| °                  | Degree                           |
| °C                 | Degrees Celsius                  |
| %                  | percent                          |
| +                  | plus                             |
| ±                  | plus, or minus                   |
| >                  | Greater than                     |
| <                  | Less than                        |
| ≤                  | Less than or equal to            |

# CHAPTER 1: INTRODUCTION

## 1.1 Background and problem statement

Ultraviolet radiation (UVR) is emitted from the sun in the form of solar ultraviolet radiation. UVR consists of three bands namely: ultraviolet A (UVA), ultraviolet B (UVB) and ultraviolet C (UVC), according to their wavelength. South Africa receives a high amount of solar UVR due to its low latitude (22° - 35° South) and clear skies almost all year round (Makgabutlane and Wright, 2015).

There are both benefits and risks associated with solar UVR exposure regarding human health (Lucas *et al.*, 2016). The benefits of solar UVR exposure include the production of vitamin D which is essential for multiple biological processes and the stimulation of melanin production which protects the skin to a certain degree against cancer (Abhimanyu and Coussens, 2017). The negative health effects associated with solar UVR exposure as a Group 1 confirmed human carcinogen (IARC, 2012), are both acute and chronic and are mostly related to the skin and the eye (Lucas *et al.*, 2016; Modenese *et al.*, 2018). The acute health effects include: erythema (redness), photo keratitis and photo conjunctivitis (Lucas *et al.*, 2016). Chronic health effects include skin cancer, ocular cataracts and immune suppression. Solar UVR exposure causes both malignant melanoma and non-melanoma skin cancer (NMSC), which is referred to as keratinocytic cancer. Keratinocytic cancer is divided into two categories: Basal Cell Carcinoma (BCC) and Squamous Cell Carcinoma (SCC) (Lucas *et al.*, 2016).

The intensity and effects of solar UVR are influenced by a number of factors that fall into three categories namely: environmental and meteorological factors such as time of day, season, geographic location (latitude), weather (cloudy or not), solar zenith angle (SZA), surface reflection and altitude; personal factors such as skin pigmentation (melanin content in African vs. Caucasian skin) and individual behaviours (during work and leisure activities); and lastly occupational factors which include anatomical site of exposure, duration of exposure and type of occupation (construction vs. car guarding) (Falk and Anderson, 2013; Bais *et al.*, 2015; Modenese *et al.*, 2018).

Outdoor work requires prolonged periods spent in the sun irrespective of ambient radiation, and each occupation requires the repetition of tasks and body positions, thus exposing certain areas of the body to higher levels of solar UVR when compared to other areas (Milon *et al.*, 2014). Therefore, it is necessary for personal exposure measurements to be carried out in different occupations, car guarding included. Solar UVR exposure measurements in various

industries have focused on larger industries such as the construction and farming industry rather than distinct industries such as the security or car guarding industry (IFA, 2015).

One of the first studies based on measuring solar UVR exposure in outdoor workers in South Africa was performed by Makgabutlane and Wright (2015). The results from the aforementioned study indicated that South African workers are exposed to up to 84.11% of the overall UVR that reach the earth. Studies conducted by Wright (2015) and by Nkogatse *et al.* (2019) during spring in South Africa have indicated overexposure of car guards, thus highlighting the importance of personal exposure measurements in car guards during different seasons, particularly those in which higher exposure is likely to occur.

The international threshold limit value (TLV) for effective irradiance is 109 J/m<sup>2</sup> per 8-hour shift, equivalent to 1.09 standard erythemal dose (SED), using the Commission Internationale de l'Éclairage (CIE) spectrum, and does not depend on skin photo-type (Lucas *et al.*, 2002; Moehrle *et al.*, 2003; ICNIRP, 2010). This limit serves as a basis for the evaluation of exposure levels, and when exceeded it may result in the risk of developing various adverse effects associated with solar UVR exposure.

Car guarding as an outdoor occupation, provides an essential service to communities by safeguarding their cars in shopping centre parking lots. In car guarding, unlike most other occupations, workers spend the entire shift outdoors thereby, increasing their exposure to solar (UVR) accompanied by the adverse health effects thereof (Nkogatse *et al.*, 2019). Being independent contractors, it remains difficult for car guards to implement the necessary protective measures relating to solar UVR exposure. Although car guards form part of an essential element in South Africa's urban landscape, their exposure to solar UVR has not been adequately studied. Therefore, this study will advance the research further by determining exposure of car guards during summer and winter. Through more research, data on solar UVR exposure will become readily available, forming a basis of educating workers on various protective measures to prevent solar UVR from becoming a serious occupational health and safety issue.

## **1.2 Aims and objectives**

The aim of this study was to quantify personal solar UVR exposure of car guards during summer and winter.

The aim was achieved through the following research objectives:

- The quantification of exposure of car guards to solar UVR during summer and winter.

- The comparison of results obtained with the TLV.
- The comparison of results obtained between the two seasons.
- The comparison of solar UVR exposure received by car guards on different anatomical areas.
- The evaluation of environmental conditions such as dry bulb temperature and relative humidity during summer and winter.
- The recommendation of suitable protective measures for participants, based on the measured levels of solar UVR.

### 1.3 Hypotheses

South Africa receives a high amount of solar UVR due to its low latitude (22° - 35° South) and clear skies almost all year round, with an average annual temperature of 22°C (Makgabutlane and Wright, 2015). Findings obtained in studies conducted by Wright (2015) and Nkogatse *et al.* (2019) indicate that car guards are exposed to high levels of solar UVR during spring. Furthermore, the level of UVR exposure differs between vertically exposed and horizontally exposed areas with horizontally exposed areas (head and shoulders) experiencing higher levels of solar UVR when compared to vertically exposed areas (face, neck and arms). However, the distribution of UVR exposure on the body depends on body posture and orientation towards the sun and the position of the sun (Milon *et al.*, 2014).

1. It was therefore hypothesized that the car guards will receive a significantly higher level of solar UVR in summer than in winter.
2. It was hypothesized that the car guards will receive lower exposure on the upper arm (vertically positioned) than on other anatomical areas (horizontally positioned) such as the shoulders and hands.

Outdoor workers such as car guards are exposed to excessive heat stress and solar UVR, thus increasing their risk of developing both heat-related and ultraviolet (UV)-related illnesses (Morabito *et al.*, 2014). According to a study performed by Beck *et al.* (2018), a positive correlation was found between wet bulb globe temperature (WBGT) and UV indices. Therefore, an increase in the one will lead to an increase in the other.

3. It was therefore hypothesized that an increase in WBGT will lead to an increase in solar UVR exposure of car guards.

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## **CHAPTER 2: LITERATURE STUDY**

### **2.1 Introduction**

Solar ultraviolet radiation (UVR) poses a great risk to human health and exposure to solar UVR plays a major role in the daily activities of outdoor workers. Outdoor workers are at particular risk of experiencing high levels of solar UVR due to prolonged hours working in the sun, which in turn increases their risk of adverse health effects associated with solar UVR exposure (Makgabutlane and Wright, 2015). To overcome the challenge of adverse effects, an in-depth understanding on factors influencing solar UVR exposure, and the effects thereof is required. This chapter aims to provide a better understanding on the following topics: solar UVR and its classes, factors influencing the intensity and effects of solar UVR reaching the earth's surface, layers and functions of the skin, benefits of solar UVR exposure, effects of solar UVR exposure on the skin and eyes, solar UVR measurements using personal dosimeters, the ultraviolet index (UVI) and the exposure limit.

### **2.2 Solar UVR and its classes**

The solar spectrum forms part of electromagnetic radiation which is known to cause a broad range of adverse health effects in humans (Bais *et al.*, 2015). Electromagnetic waves have both electric and magnetic properties and are divided into six categories namely: radio waves, infrared waves, X-rays, gamma rays, visible light and ultraviolet (UV) waves. The most commonly found and known electromagnetic wave related to this study is the UV wave which is responsible for most of the deleterious effects experienced by humans (Bais *et al.*, 2015). UV waves are emitted from the sun in the form of solar radiation. Ultraviolet radiation (UVR) is divided into three bands, according to their wavelength: ultraviolet A (UVA), ultraviolet B (UVB) and ultraviolet C (UVC). UVA radiation has a wavelength of 315 - 400 nanometres (nm) and accounts for 95% of the total radiation reaching the earth's surface. The remaining 5% is made up of UVB radiation with a wavelength of 280 - 315 nm. UVC radiation has a wavelength of 100 – 280 nm (ICNIRP, 2010). The amount of both UVB and UVC radiation reaching the earth's surface is largely influenced by the ozone levels in the stratosphere with UVC radiation being prevented from reaching the earth's surface due to its absorption by the stratosphere (ICNIRP, 2010; Widel *et al.*, 2014; Bais *et al.*, 2015).

## **2.3 Factors influencing the intensity and effects of solar UVR reaching the earth's surface**

The various factors that affect the intensity of solar UVR exposure are categorized into environmental and meteorological factors, occupational factors and personal factors. Environmental and meteorological factors include: stratospheric ozone, clouds, solar zenith angle (SZA), time of day, season, geographic location (latitude and altitude), surface reflection, and the presence of aerosols. Occupational factors include the anatomical area of exposure, duration of exposure and type of occupation. Personal factors include skin pigmentation (dark skin vs light skin – Fitzpatrick skin types) and individual behaviour practices regarding exposure and protective measures at work and during off-duty activities.

### **2.3.1 Environmental and meteorological factors**

Environmental and meteorological factors play an important role in the amount of solar UVR received by outdoor workers since these factors can either enhance or attenuate exposure, depending on the strength of the sun and the amount of solar UVR reaching the earth's surface (Modenese *et al.*, 2018). Heat stress, such as temperature and humidity, together with solar UVR exposure causes a range of adverse health effects (Yi and Chan, 2017). These factors influence the intensity of solar UVR perceived by workers, as an increase in temperature, results in an increase in personal exposure to solar UVR (US FDA, 2017a).

#### **2.3.1.1 Stratospheric ozone**

Ozone (O<sub>3</sub>) is a triatomic molecule found in the troposphere (10%) and in the stratosphere (90%). The ozone layer refers to the majority of ozone present in the stratosphere. Stratospheric ozone is produced in the following manner: (1) the breaking down of an oxygen molecule into two separate atoms by solar UVR, (2) collision of these atoms with other oxygen molecules and (3) formation of ozone (Hegglin *et al.*, 2015).

Stratospheric ozone (i.e. the ozone layer) serves as a UV filter, absorbing harmful UV radiation (Hegglin *et al.*, 2015). Morgenstern *et al.* (2008) and Newman *et al.* (2009) investigated climate change and found that drastic changes in temperature and stratospheric depletion are likely to occur due to a loss in ozone. Since solar UVR is absorbed by the ozone layer, a depletion in ozone causes an increase in the amount of solar UVR reaching the earth's surface, thereby increasing the risk of adverse effects in humans and the atmosphere (Chipperfield *et al.*, 2015). UV irradiance, which refers to the amount of electromagnetic radiation received from the sun per unit area, has been found to increase at wavelengths below 320 nm due to a decrease in stratospheric ozone (De Bock *et al.*, 2014). Aerosols and trace gases from

industries cause a decline in the stratospheric ozone, thus contributing to a higher UV irradiance (Krzýscin *et al.*, 2011; Fitzka *et al.*, 2012).

### 2.3.1.2 Clouds

Clouds may increase or decrease the amount of solar UVR reaching the earth's surface, depending on the amount and type of cloud; surface reflection, refraction or scattering (Bais *et al.*, 2015). Complete cloud cover reduces UVR exposure by half, but it could also enhance UVR exposure, depending on the percentage of cloud cover; the location of the cloud and the optical thickness and liquid content (water) of the clouds (ICNIRP, 2010; Makgabutlane and Wright, 2015; Modenese *et al.*, 2018). The increase in UVR exposure by cloud cover occurs during cloudy conditions when the water vapor in the clouds absorb solar infrared radiation without a warning sensation such as warming or reddening of the skin (ICNIRP, 2010).

### 2.3.1.3 Solar Zenith Angle

The intensity of solar UVR is highly dependent on the Solar Zenith Angle (SZA). SZA, as indicated in Figure 1, is the angle between the observer and the centre of the sun's disc (i.e. the zenith) which is between  $0^{\circ}$  and  $90^{\circ}$  (Makgabutlane and Wright, 2015). The SZA has an inverse influence on the sun's intensity reaching the ground i.e. the larger the SZA, the lower the intensity of the sun's rays since the ray scatters over a larger surface area of the earth and vice versa. Seasonal and daily variations of the SZA exist. For example, during summer the SZA is smaller, resulting in a stronger ray of sun, whilst during winter, the intensity of the sun is lower due to a larger SZA (Makgabutlane and Wright, 2015).

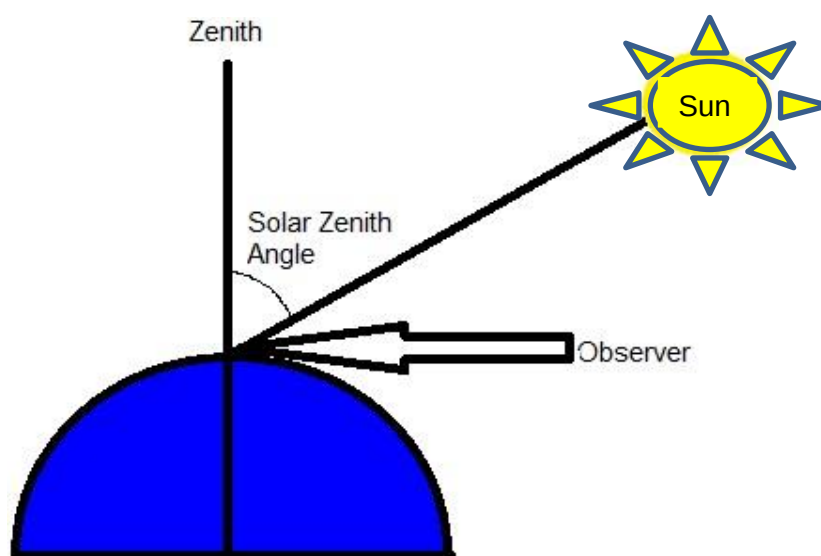


**Figure 1:** Schematic representation of the Solar Zenith Angle (SZA) (SACS, 2011).

#### 2.3.1.4 Time of day

The position of the sun changes throughout the day, with it being the highest at solar noon (US FDA, 2017a). Seventy-five percent of solar UVR exposure occurs between 09:00 am – 03:00 pm while 20 – 30% of exposure occurs between 11:00 am – 01:00 pm (ICNIRP, 2010; Modenese *et al.*, 2018). The reason behind this large difference in exposure is because the sun's rays travel a shorter distance through the atmosphere at noon, when compared to early morning and late afternoon. Therefore, time of day plays a crucial role in determining the levels of solar UVR experienced by workers (Gordon, 2013).

#### 2.3.1.5 Season

The intensity of the sun is dependent on the tilt of the earth on its axis and the angle of the sun resulting in seasonal variations. As the earth rotates around the sun, it tilts at a 23.5° angle, causing one hemisphere to face the sun more than the other hemisphere. The hemisphere tilting towards the sun will receive a higher dose of solar UVR when compared to the other hemisphere. For example: if the Southern hemisphere tilts towards the sun, it will experience summer because the SZA is greater and UVR more intense (Harris, 2018). This will also cause the sun to form a clear direct angle with which it strikes the earth's surface, resulting in an increase in the amount of solar UVR reaching the earth's surface (US FDA, 2017a). The opposite will occur in the Northern hemisphere which will experience winter as the earth tilts further away from the sun, thus decreasing the levels of solar UVR reaching the earth's surface (US FDA, 2017a; Harris, 2018). The delivery of heat energy from the sun will be higher in summer than in winter, which explains the increased temperatures and higher sun intensity during summer (Harris, 2018).

#### 2.3.1.6 Geographic location (latitude and altitude)

Latitude is a measure of the distance from the equator (North – South), while altitude refers to the height of an object above sea level. Solar UVR is stronger in areas closer to the equator because the UV ray travels a shorter distance through the atmosphere and the ozone layer is much thinner to absorb the UV rays. As a result of this thin layer of the ozone, exposure to solar UVR is increased at areas closest to the equator (US FDA, 2017a). An increase in altitude increases the levels of solar UVR reaching the earth, thus leading to an increase in solar UVR exposure (ICNIRP, 2010; Modenese *et al.*, 2018). This increase in solar UVR at higher altitudes is due to a decrease in atmosphere meant to absorb solar UVR (US FDA, 2017a). A 4% increase in sunburn is prevalent with every 300 metres (m) increase in altitude (ICNIRP, 2010; Modenese *et al.*, 2018).

#### 2.3.1.7 Surface reflection

Surface reflection refers to the ratio of the reflected radiation to the incident amount of radiation (Bais *et al.*, 2015). Reflectance can be explained by the albedo phenomenon which expresses the ability of a surface to reflect sunlight (ICNIRP, 2010; Modenese *et al.*, 2018). The upward reflection of radiation from a surface is scattered by air molecules and particles, thus increasing the radiation received by a bystander (Bais *et al.*, 2015). The intensity of the UV ray is highly dependent on the surface from which it is reflected. The higher the reflectivity of a surface, the greater the effect of solar UVR on the bystander. For example, snow has a high reflectance rate of 90% thus increasing UV intensity which ultimately increases exposure. On the other hand, grass has a low reflectance rate of less than 1% and will have a lower intensity of solar UVR. This phenomenon explains the reason for having the higher UV intensity in spite of some form of shade being available (ICNIRP, 2010; Modenese *et al.*, 2018). The angle of incidence plays a role in the amount of radiation reflected from a surface and is dependent on season and latitude (Bais *et al.*, 2015).

#### 2.3.1.8 Aerosols

Aerosols are solid or liquid particles that remain suspended in air or gas. Aerosols are either natural (sea salt), anthropogenic (organic particles) or a combination of both. They affect the transfer of solar radiation into the atmosphere when encountering solar photons (visible-light particles). The scattering and absorption of sunlight depends on the aerosols shape, size and chemical composition (Bais *et al.*, 2015).

### 2.3.2 Occupational factors

Occupational factors are influenced by both environmental and personal factors. The influence of environmental factors on outdoor worker exposure depends on the area of work, job description and time required to carry out a particular task. For example, roofers usually work during the day when exposure levels are high. The working area may be constructed out of zinc which is a reflective surface enhancing exposure to solar UVR (Modenese *et al.*, 2018). This type of work requires the repetition of tasks in certain bodily positions, thus resulting in overexposure of certain anatomical areas when compared to others (Milon *et al.*, 2014). Personal factors are dependent on the skin pigmentation of the worker and the measures taken by individual workers to protect themselves against solar UVR exposure (Zink *et al.*, 2017).

### 2.3.2.1 Anatomical area of exposure

Different areas of the body experience different levels of solar UVR, depending on the task at hand (Milon *et al.*, 2014). Generally, the head, neck, shoulders, face and forearms were found to be frequently exposed to solar UVR during outdoor work. This occurs because they are usually left unprotected by clothing and experience repetitive motions, thus allowing these areas to be susceptible to high doses of solar UVR. This in turn, increases their risk to squamous cell carcinoma (SCC) and basal cell carcinoma (BCC) (Milon *et al.*, 2014). The study conducted by Milon *et al.* (2014) found that workers' shoulders received 2 – 2.1 times more ambient radiation when compared to the face. The position of the sun and the posture orientation of the body play a significant role in the exposure dose of solar UVR on horizontally and vertically exposed areas. For example, during winter, the sun is lower and the SZA is higher, therefore vertically exposed bodily areas experience more direct sunlight than horizontally exposed areas. Ambient irradiation has been reported as higher during summer than winter, therefore horizontally and vertically exposed areas experienced high levels of solar UVR due to a smaller SZA during summer (Milon *et al.*, 2014).

### 2.3.2.2 Duration of exposure and type of occupation (indoor work vs outdoor work)

Outdoor work, together with increased temperatures, is a cause for concern when compared to indoor work. Indoor workers are workers spending most of their time inside buildings. The buildings only allow sun to enter through windows, thereby limiting indoor worker exposure to only breakfast and lunch breaks and while traveling to and from work. Outdoor workers are workers who spend a minimum of 3 hours per day between 09:00 am and 03:00 pm outside during a week and have an increased risk of adverse health effects associated with solar UVR exposure (Janda *et al.*, 2014; Makgabutlane and Wright, 2015). According to a study performed by Nahar *et al.* (2013), outdoor workers are exposed to solar UVR levels six to eight times higher than those of indoor workers.

Solar UVR exposure measurements have focused on larger industries such as the construction and farming industry rather than distinct industries such as the security or car guarding industry (IFA, 2015). One of the first studies based on measuring personal solar UVR exposure on outdoor workers in South Africa was performed by Makgabutlane and Wright (2015). The results from the aforementioned study indicated that South African outdoor workers are exposed to up to 84.11% of the overall solar UVR reaching the earth. The authors mention that detailed research is required for measuring long-term solar UVR exposure in various outdoor occupations throughout South Africa and that the use of electronic dosimeters will prove to be beneficial (Makgabutlane and Wright, 2015). In a pilot study wherein the solar

UVR exposure of one car guard was measured during spring in South Africa, the car guard's exposure was found to exceed the occupational exposure limit (OEL) (Wright, 2015). Similar findings were obtained from a study reported by Nkogatse *et al.* (2019) assessing the exposure of car guards in South Africa to solar UVR during spring. According to Nkogatse *et al.* (2019), overexposure of car guards to solar UVR is likely to occur during summer because of the high levels of solar UVR reaching the earth's surface.

### **2.3.3 Personal factors**

The levels of solar UVR exposure received by individuals are influenced by personal factors such as skin pigmentation and individual behaviours. Individual behaviours are assessed to evaluate the measures taken by workers to protect themselves against solar UVR exposure. Skin pigmentation plays a role in the level of risk likely to occur with exposure as light-skinned individuals are more likely to experience sunburn amongst other adverse health effects than dark-skinned individuals.

#### **2.3.3.1 Individual behaviour**

Wright and Albers (2011) indicated that minor attempts have been made thus far regarding individual attributes such as knowledge, behaviour and attitudes towards sun exposure in South Africa. Exposure can be prevented through various methods such as protective clothing (long-sleeved clothes, sun hats, dark coloured clothing), the application of sunscreen with a high sun protection factor (SPF), eye protection (sunglasses) and where possible, standing/working in the shade (Lucas *et al.*, 2016). Outdoor workers who do not protect themselves against the sun experience 25.5 – 54.6% of the total solar UVR reaching the earth's surface annually (Milon *et al.*, 2014).

A study conducted by Zink *et al.* (2017) indicated that most outdoor workers are males who spend more than 21-hours per week in the sun. Sun protective measures are rarely adhered to as most outdoor workers find it difficult to implement. In addition, few workers acknowledged the SPF on sunscreens when purchasing it, indicating that education regarding sun protection is a necessity (Zink *et al.*, 2017). Other studies have also indicated that men are less likely to implement sun protective behaviours even though they have a certain degree of knowledge regarding the adverse health effects associated with sun exposure (Backes *et al.* 2017; Zink *et al.*, 2017). The findings of the study by Zink *et al.* (2017) are significant since it was the first study conducted in Germany on outdoor workers investigating protective behaviours since non-melanoma skin cancer (NMSC) was formally introduced as an occupational disease in 2015. The application of sunscreen amongst outdoor workers was rare when compared to the

wearing of sun hats and long-sleeved clothing (Backes *et al.*, 2017; Nkogatse *et al.*, 2019). It has also been found that education plays a significant role in decreasing risky behaviour amongst outdoor workers (Backes *et al.*, 2017; Zink *et al.*, 2017; Nkogatse *et al.*, 2019).

### 2.3.3.2 Skin pigmentation

Fitzpatrick skin photo types describes the different skin types in terms of their response to solar UVR exposure. The skin types form a basis in understanding individual risk for sunburn and solar UVR associated health effects (ICNIRP, 2010). The two types of melanin include *eumelanin* and *pheomelanin*. *Eumelanin* absorbs UVR which removes reactive oxygen species (ROS) and prevents molecular damage caused by solar UVR exposure and is therefore referred to as a photoprotector. *Pheomelanin* on the other hand is a photosensitizer and absorbs UVR, producing photo unstable ROS which causes molecular damage and may stimulate cancer formation (ICNIRP, 2010; Nasti and Timares, 2015).

Melanin found in keratinocytes serve as a sunscreen, preventing the penetration of UVR into deeper layers of the skin. *Eumelanin* is found in populations with darker-skin types, while *pheomelanin* increases in celtic types, and is found in populations with lighter-skin. Since *eumelanin* absorbs UVR and is found in darker-skin (skin types IV – VI), this skin type is less sensitive to the harmful ray of solar UVR and the possibility of the skin to tan or become sunburnt is unlikely. Lysosomal enzyme degradation occurs in lighter-skin (skin types I – III), thus reducing the amount of *eumelanin* in keratinocytes, decreasing the protective function in the skin and increasing susceptibility to sunburn, tanning and other adverse health effects (Brenner and Hearing, 2007; Nasti and Timares, 2015). Each skin type reacts differently when exposed to solar UVR, thus causing a variation in the type and degree of adverse effects associated with solar UVR exposure. For example, skin photo-type I is extremely sensitive to solar UVR, thus causing sunburn immediately after exposure and increasing the risk of skin cancer due to the skin being melano-compromised. Skin photo-type VI does not burn that easily and has a higher dose of melanin content, reducing the risk of adverse effects (Fitzpatrick, 1988; ICNIRP, 2010). Table 1 below indicates the various skin types and their sensitivity as described by Fitzpatrick (1988) together with the classification of the melanin content by ICNIRP (2010).

**Table 1:** Fitzpatrick skin photo-type classification, sunburn susceptibility and tanning ability (Fitzpatrick, 1988; ICNIRP, 2010; Makgabutlane and Wright, 2015).

| <b>Skin Photo-type</b> | <b>Skin colour</b> | <b>Constitutive characteristics</b>                   | <b>Sunburn History</b>                          | <b>Tanning ability</b> | <b>Sensitivity</b>     | <b>UVR eliciting sunburn (SED)*</b> | <b>ICNIRP groups</b> |
|------------------------|--------------------|-------------------------------------------------------|-------------------------------------------------|------------------------|------------------------|-------------------------------------|----------------------|
| I                      | White              | Fair skin, blonde hair, blue eyes                     | Always burns on minimal sun exposure            | No tan                 | Extremely sensitive    | 2 - 3                               | Melano-compromised   |
| II                     | White              | Fair or freckled skin, blonde or red hair, green eyes | Readily burns                                   | Light tan              | Very sensitive         | 2.5 - 3                             | Melano-compromised   |
| III                    | White/Light Brown  | Brown hair; blue, hazel or brown eyes                 | May burn on regular exposure without protection | Medium tan             | Moderately sensitive   | 3 - 5                               | Melano-competent     |
| IV                     | Light Brown        | Brown hair, dark eyes                                 | Rarely burns                                    | Dark tan               | Relatively tolerant    | 4.5 - 6                             | Melano-competent     |
| V                      | Brown              | Dark brown or black hair, brown eyes                  | May burn                                        | Natural brown skin     | Very variable          | 6 – 20                              | Melano-protected     |
| VI                     | Black              | Dark brown or black hair, brown eyes                  | May burn, although difficult to notice          | Natural black skin     | Relatively insensitive | 6 - 20                              | Melano-protected     |

Note: SED (Standard Erythema Dosage)

## **2.4 Layers and functions of the skin**

The skin is the largest single organ in the body and serves as an interface between the human body and the external environment (Ng and Lau, 2015; HSE, 2018). It consists of three important layers: the epidermis, the dermis and the hypodermis (Ng and Lau, 2015; Lai-Cheong and McGrath, 2017; HSE, 2018). Properties of the skin include: water preservation, thermoregulation, vitamin D production, reduction in effects caused by solar UVR, and protection against injury, infection, trauma and hazardous substances (US FDA, 2017a; HSE, 2018).

### **2.4.1 The epidermis**

The epidermis is the outermost elastic layer affected by UVB radiation and is subdivided into five layers; namely: the stratum corneum (horny layer), the stratum lucidum (clear layer), the stratum granulosum (granular layer), the stratum spinosum (prickly layer), and the stratum basale (basal layer) (Ng and Lau, 2015; US FDA, 2017b; HSE, 2018). The stratum spinosum and the stratum basale jointly form the Malpighian layer (Ng and Lau, 2015). The stratum basale consists out of keratinocytes, melanocytes and Merkel cells (Arda *et al.*, 2014). Keratinocytes, actively dividing cells, make up 95% of the cells in the epidermis (Gordon, 2013; Arda *et al.*, 2014). Melanocytes, Merkel cells and Langerhans cells make up the remaining 5% of cells (Lai-Cheong and McGrath, 2017). The melanin content of the skin, responsible for skin pigmentation, is produced by melanocytes and protects the deoxyribonucleic acid (DNA) from harmful UV radiation caused by sun exposure through the production of melanin which in turn darkens the skin. Merkel cells play a role in tactile sensation and are sensitive to light touch (Arda *et al.*, 2014). The thick layer of the epidermis, the stratum spinosum, contains Langerhans cells. The Langerhans cells are antigen-presenting dendritic cells, protecting the body from foreign bodies (Arda *et al.*, 2014). The stratum lucidum forms part of the stratum corneum and is found in areas of thick skin such as the palm of the hand or the sole of the feet (Ng and Lau, 2015). The stratum corneum is the superficial layer which protects the other layers of the skin (Gordon, 2013).

### **2.4.2 The dermis**

The dermis is found between the epidermis and the hypodermis and is mainly affected by UVA radiation. The dermis contains specialized cells such as the sweat glands, sebaceous glands and hair follicles (Gordon, 2013; US FDA, 2017b; HSE, 2018). Sweat glands and hair follicles are responsible for temperature regulation, whilst sebaceous glands produce oil which protect the hair against bacteria and dust (HSE, 2018). The dermis is divided into two layers: the

papillary dermis and the reticular dermis. The papillary dermis has several blood vessels and sensory nerve endings and is in contact with the basement membrane zone which separates the epidermis from the dermis. The reticular dermis is the main component of the dermis and makes contact with the hypodermis (Lai-Cheong and McGrath, 2017).

### **2.4.3 The hypodermis**

The hypodermis is also known as the subcutaneous layer or the subcutis and is the innermost layer of the skin consisting of connective tissue, lipocytes, blood vessels and nerves. The subcutis allows fat storage which serves as an insulator for internal organs. Lipocytes produce leptin which regulates appetite and metabolic energy (Lai-Cheong and McGrath, 2017; HSE, 2018). Blood vessels and nerves play a role in thermal regulation and shock absorption (Gordon, 2013).

## **2.5 Benefits of solar UVR exposure**

Heat and light energy emitted by the sun improves overall well-being and stimulates blood circulation. Exposure to solar UVR is necessary for the body to produce vitamin D as minimal amounts are obtained from the diet. Vitamin D plays an important role in increasing calcium and phosphorus absorption from one's diet. In addition, vitamin D plays a fundamental role in skeletal development, immune function and blood cell formation. Exposure to sunlight should be limited to 5 – 15 minutes, 2 – 3 times a week during summer, depending on latitude and skin photo type, for adequate vitamin D production and the avoidance of negative health effects. Phototherapy has been found to be beneficial in the treatment of various diseases such as rickets, jaundice, eczema and psoriasis, provided that exposure is carried out under medical supervision ensuring that the benefits outweigh the risks (US FDA, 2017a; WHO, 2019a).

## **2.6 Health effects of solar UVR exposure on the skin and eyes**

Effects associated with solar UVR exposure are determined by an individual's age, health and skin type. The elderly (over 50 years), young (5 years) and immune compromised individuals are more susceptible to the effects caused by solar UVR exposure than their healthier and middle-aged counterparts (US FDA, 2017b). Outdoor workers are also highly susceptible to the adverse effects caused by solar UVR exposure as most of their time is spent in direct sunlight with little to no shade available. The eye and the skin are the main organs affected by solar UVR exposure. Biological effects of solar UVR exposure involve DNA damage, gene mutation, immune suppression, oxidative stress and inflammation which increases ageing of the skin and the development of skin cancer (Maden *et al.*, 2010; Narayanan *et al.*, 2010).

Solar radiation affects biological tissues through photochemical effects (400 – 550 nm) or thermal effects (infrared radiation, 600 – 700 nm). Photochemical effects involve the absorption of energy from light by chromophores in DNA whilst the thermal effects involve the absorption of light energy which increases in the tissues and is converted into heat energy. The effects of the photochemical and thermal mechanism of the skin and eye depend on the wavelength of light energy and the position of the sun at a given time (Modenese *et al.*, 2018).

The scattering caused by clouds and reflection from different surfaces are the main sources of ocular exposure to solar UVR resulting in outdoor workers receiving  $\pm 10\%$  of the annual UV radiation. The dose of solar UVR that the eyes receive depends on the angle of the sun. In other words, damage caused to the eyes by solar UVR exposure occurs in the morning (08:00 am – 10:00 am) and in the afternoon (02:00 pm – 04:00 pm) when the solar elevation angle is at its lowest (between 30° and 50°). The skin however, experiences high doses of solar UVR during noon or peak hours (10:00 am – 02:00 pm) when the sun's elevation angle is at its highest i.e.  $> 60^\circ$ , and this is when adverse effects on the skin occur (Sasaki *et al.*, 2011; Gao *et al.*, 2012).

## **2.6.1 Acute health effects**

### **2.6.1.1 Sunburn**

Sunburn, manifesting as erythema or blistering, is the first sign indicating that damage to the skin has occurred. It is characterized by reddening of the skin (US FDA, 2017c; WHO, 2019a). The process of sunburn occurs as follows: (1) UV exposure; (2) damage to epidermal cells; (3) increased blood flow to exposed skin; (4) reddening of the skin, and skin becomes warm; (5) chemicals released from damaged cells; (6) perception of pain and a burning sensation; (7) removal of damaged skin by white blood cells through the peeling of skin; (8) replacement of damaged skin by new skin (US FDA, 2017c). Sunburn varies in severity depending on the duration of exposure. Mild to moderate sunburn causes reddening of the skin which lightens within 24 hours and disappears after a few days. Severe to extreme sunburn causes a deep reddening of the skin together with blisters. This type of sunburn takes longer to heal and causes the skin to peel. As the skin peels, the layers beneath are left unprotected, thus increasing the risk of further UV damage (WHO, 2019a).

### **2.6.1.2 Sun tanning**

Tanning is the process of skin darkening in which the skin produces melanin in high concentrations, protecting itself against UV damage. This procedure might seem attractive to light-skinned individuals, however, it is a mere indication of damage occurring to the skin. The

type of tanning depends on the UV-wavelength, i.e. UVA-induced tanning causes immediate pigmentation, whereas UVB-induced tanning causes delayed pigmentation (US FDA, 2017c; WHO, 2019a).

#### 2.6.1.3 Photoaging

Ageing consists of intrinsic and extrinsic ageing. Intrinsic ageing occurs as one gets older (time-related), whereas extrinsic ageing is mainly due to environmental factors such as solar UVR exposure (Nicol and Fenske, 1993; Martires *et al.*, 2009). Ageing caused by solar UVR exposure is referred to as photoaging (US FDA, 2017c). Photoaging occurs on areas of the body that are frequently exposed to the sun such as the face, neck and shoulders. Signs of photoaging include skin thickening, dryness, roughness and keratosis. The process of photoaging occurs as follows: (1) exposure to solar UVR, (2) disruption in the production of collagen and elastin fibres (3) skin regenerating enzymes become hyperactive, (4) degradation of collagen fibres and loss of shape of elastin fibres (5) structural and functional changes of the skin together with irregular skin pigmentation, (6) ageing of the skin (Fisher *et al.*, 2002; Yaar and Gilchrest, 2007; Sasaki *et al.*, 2011; Behar-Cohen *et al.*, 2014).

#### 2.6.1.4 Photo keratitis and photo conjunctivitis

Exposure of the eye to UV irradiation between 180 – 400 nm creates a sunburn effect on sensitive tissues, leading to an inflammatory response of the cornea (photo keratitis) or the conjunctiva (photo conjunctivitis). The reactions, albeit short-lived (24 – 48 hours), are painful and occur hours after exposure. (Behar-Cohen *et al.*, 2014; US FDA, 2017c; WHO, 2019a). Photo keratitis is referred to as snow blindness commonly found in individuals living at high altitudes with large snow cover, causing high levels of UVB ground reflection into the cornea. Snow blindness is also found in individuals participating in sports requiring snow such as skiers and climbers (US FDA, 2017c; WHO, 2019a).

### 2.6.2 Chronic health effects

#### 2.6.2.1 Skin cancer

According to the International Agency for Research on Cancer (IARC), solar UVR is classified as a Group 1 confirmed human carcinogen (i.e. carcinogenic to humans) (IARC, 2012). Skin cancer is becoming a major concern in individuals occupationally exposed to solar UVR (IARC, 2012) and accounts for 30% of all cancers in South Africa (Makgabutlane and Wright, 2015). South Africa is listed as the country with the second highest incidence of skin cancer after Australia (Herbst, 2017). Elsewhere, solar UVR is responsible for 50 – 90% of melanoma

and basal cell carcinoma (BCC) skin cancer cases and 50 – 70% of squamous cell carcinoma (SCC) cases (Lucas *et al.*, 2006).

UVA radiation penetrates deeper into the skin when compared to UVB radiation, thus causing significant damage (elastosis) (Brenner and Hearing, 2007). UVB radiation damages DNA while UVA radiation has an indirect effect by forming free radicals, thus damaging cell membranes (Maden *et al.*, 2010; Narayanan *et al.*, 2010). Energy released from solar UVR into the skin is absorbed by DNA which forms cyclobutene pyrimidine dimers, leading to immune suppression. Mutations of the p53 genes caused by UVR exposure impairs the ability of DNA to repair damage resulting in the dysregulation of apoptosis. The apoptosis further leads to the mitosis of keratinocytes and the subsequent growth of skin cancer (Marshall *et al.*, 2000; Benjamin and Ananthaswamy, 2007; Brenner and Hearing, 2007).

#### *2.6.2.1.1 Malignant melanoma*

Melanoma skin cancer, characterised by a mole which changes shape, colour and size; is derived from melanocytes (Craythorne and Al-Niami, 2017; WHO, 2019a). Malignant melanoma makes up 3% of skin cancer related cases and is responsible for 75% of skin-cancer related deaths because it spreads easily to other parts of the body. The spread occurs from the skin through the lymph nodes into organs such as the liver, lungs, brain and bones (EPA, 2017; MRF, 2019). The induction of malignant melanoma is a result of immune suppression of the skin, initiation of melanocytic division, production of free radicals and damage of melanocytic DNA. Melanoma skin cancer is caused by mutations of the p16 gene (Gordon, 2013). This type of cancer affects the lighter-skinned population 20 times more than the darker-skinned population (Narayanan, 2010; American Cancer Society, 2012).

#### *2.6.2.1.2 Non-melanoma skin cancer (NMSC)*

Non-melanoma skin cancers (NMSC), now referred to as keratinocytic cancer, arise from epidermal derived cells. There are two types of non-melanoma skin cancers, namely basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). BCC and SCC frequently occur on areas of the body that remain unprotected from the sun such as the face, neck, ears, and arms. Keratinocytic cancer is dependent on cumulative lifetime exposure, implying that outdoor workers have an increased risk of developing this type of cancer compared to indoor workers (WHO, 2019a).

a) Basal cell carcinoma (BCC)

BCC is a result of chronic intermittent sun exposure where the pluripotent cells develop mutations in the p53 gene (Gordon, 2013; Craythorne and Al-Niami, 2017). These tumours grow slowly and can be aggressive depending on their histological subtype. They seldom metastasize and are likely to arise in individuals over the age of 40. BCC characteristics include: pearly nodules, non-healing scabs, red patches, and thickened white areas on the skin. Histological subtypes are categorised according to low-risk and high-risk subtypes. Low-risk subtypes can either be superficial BCCs or nodular BCCs. Superficial BCCs are well-defined red, pink or brown plaques that expand slowly and are found on the trunk. Nodular BCCs are common and present as pearl-white nodules with telangiectasia (dilated blood vessels appearing on the surface of the skin as “spider veins”). High-risk subtypes grow aggressively and deeper in the skin (Craythorne and Al-Niami, 2017).

b) Squamous cell carcinoma (SCC)

SCC is a result of cumulative habitual sun exposure (Porter, 2011; Firnhaber, 2012). Clinical manifestations differ, although they generally appear as lesions resembling warts that grow rapidly. SCC presents itself as plaques, papules, nodules and smooth, crusty or erosive lesions. A malignant tumour arises from the squamous keratinocytes in the epidermis or the mucous membranes as red papules with rough surfaces (Porter, 2011; Firnhaber, 2012; Craythorne and Al-Niami, 2017). These papules eventually become nodules which may start bleeding. In due course, the tumour ulcerates and occupies the tissue spaces below the tumour. It has been found that any lesion that does not heal is a sign of SCC, provided that these lesions occur on susceptible areas (Porter, 2011; Firnhaber, 2012). Risk factors for SCC during work activities include: solar UVR exposure, immunosuppression, chronic scarring (lupus, burns), smoking, arsenic and human papillomavirus infections (Craythorne and Al-Niami, 2017).

#### 2.6.2.2 Ocular cataracts

Cataracts are the leading cause of blindness worldwide and appears with age or excessive solar UVR exposure. Proteins in the eye loosen from their original position and tangle with accumulation of other pigments, resulting in a loss of lens transparency which produces clouded vision (EPA, 2017; WHO, 2019a). According to the World Health Organization (WHO), 20% of blindness caused by cataracts is a result of excessive exposure to solar UVR. Consequently, UVB plays a major role in increasing the risk in the development of cataracts. However, UVA may trigger a reaction in the absence of oxygen which also leads to the development of cataracts. (WHO, 2019a).

### 2.6.2.3 Immune suppression

UVB exposure causes immune suppression by means of: (1) production of immunosuppressive mediators, (2) prevention of antigen-specific immune response stimulation, (3) generation of suppressor cells, (4) prevention of effector and memory T-cell activation and (5) immune suppression (IARC, 2012). UVA immunosuppression alters redox equilibrium causing the migration of antigen-presenting cells, thus preventing T-cell activation and the production of suppressor cells (Norval *et al.*, 2008).

## 2.7 Solar UVR measurements using personal dosimeters and hand-held UVI monitors

In order to obtain the levels of solar UVR that outdoor workers, particularly car guards are exposed to, and to identify the health effects likely to arise with exposure, personal solar UVR measurements are required. This can be achieved by using solar UVR measuring instruments. There are a variety of measuring instruments available for measuring solar UVR exposure. However, technological advances have made it possible for electronic UV dosimeters to replace the polysulfone (PS) films (Allen and McKenzie, 2010). PS films are chemical responsive films which change in absorbance in a dose-dependent manner upon exposure to solar UVR (Herlihy *et al.*, 1994). Electronic dosimeters are re-usable, cost-effective and record measurements at intervals of seconds, hours and days (Allen and McKenzie, 2010). This study utilized the GENESIS-UV dosimeter (GENeration and Extraction System for Individual ExpoSure) for personal exposure measurements and anatomical extrapolation, and the hand-held UV monitor for measuring ambient UVR (Oregon Scientific, 2006; Wittlich, 2015).

### 2.7.1 Generation and Extraction System for Individual Exposure (Genesis-UV)

The Genesis-UV dosimeter was manufactured in Germany, and the Institut fuer Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA) has developed a campaign focusing on measuring task-related exposures by means of this dosimeter. This measurement system is relatively new and has been successfully used in quantifying exposures in over 100 occupations in Germany, since 2014 (IFA, 2015; Wittlich, 2015). The Genesis-UV dosimeter measures both UVA and UVB radiation through sensors and records task-specific exposure. This dosimeter provides a detailed approach in measuring personal long-term UVR exposures (Wittlich, 2015), thus making it possible to overcome the occupational health problem that outdoor workers face as well as filling the gap in research associated with occupational exposures.

### **2.7.2 Hand-held UV monitor**

The hand-held UV monitor used in this study was manufactured for Oregon Scientific (IDT Technology Limited, Hung Hom, Kowloon, Hong Kong). This portable UV monitor is a lightweight (78 g), compatible device (width = 4.445 cm, height = 7.94 cm, diameter = 1.901 cm) suitable for measuring the UV level and temperature. It comprises of a UV index and measurement icon, an exposure alarm, a clock timer, temperature display, skin type and sun protection factor (SPF) icon and is powered by lithium ion batteries. The sensor has a spectral response matching the erythral action spectrum (EAS) of the skin which enables the dosimeter to obtain a UV measurement similar to that experienced by human skin and calculates maximum exposure time depending on skin type and SPF selected by the user (Oregon Scientific, 2006).

## **2.8 The ultraviolet index (UVI)**

The UV index (UVI) is a simplified manner in which workers and the public receive notification of a single number indicating the intensity of solar UVR as well as the ability of the sun to cause damage to the skin and eyes. The UVI was founded based on the erythema action spectrum (EAS) which is dependent on the wavelength of solar UVR required to cause sunburn (erythema). The ability of the sun to cause erythema is represented by the UVI value which is obtained by multiplying the erythral irradiance ( $\text{W/m}^2$ ) by 40 (Fioletov *et al.*, 2010).

Work on solar UVR was initially conducted in Canada in 1992 and was embraced globally by WHO in 1994 (SSAWC, 2016). The UVI in Table 2 is aimed at enhancing public awareness to solar UVR exposure. Each UVI range indicates the risk of exposure and protective measures to be implemented. Protective measures should be implemented at moderate levels of exposure ( $\text{UVI} > 3$ ), and additional measures should be taken when the UVI exceeds 8 (SSAWC, 2016). This index has proved to be valuable to climatologists, health professionals, especially eye specialists and dermatologists, and the overall population in terms of dangers associated with UV exposure and the necessary protective measures required (Zaratti *et al.*, 2014).

**Table 2:** UV exposure index and recommended protective measures (WHO, 2019b).

| UV index range | Risk level if unprotected | Recommended protective measures                                                                                                                                                               |
|----------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| < 2            | Low                       | Sunscreen for fair skinned individuals.                                                                                                                                                       |
| 3 – 5          | Moderate                  | Sunscreen, sunglasses, hat and shirt. Avoid being outdoors at midday.                                                                                                                         |
| 6 – 7          | High                      | Sunscreen, sunglasses, wide-brimmed hat, loose fitting clothing. Avoid being outdoors between 11:00 am and 02:00 pm.                                                                          |
| 8 – 10         | Very high                 | Sunscreen, sunglasses, wide-brimmed hat, loose fitting, long-sleeved clothing. Avoid being outdoors between 11:00 am and 02:00 pm. Drink plenty water to prevent dehydration.                 |
| 11+            | Extreme                   | Sunscreen, sunglasses, wide-brimmed hat, loose fitting, long-sleeved clothing, and long pants. Avoid being outdoors between 10:00 am and 03:00 pm. Drink plenty water to prevent dehydration. |

Note: UV (Ultraviolet)

## 2.9 Heat stress measurements using the QUESTemp<sup>®</sup>32/34

The QUESTemp<sup>®</sup>32/34 Area Heat Stress Monitor was manufactured by TSI Incorporated, Minnesota, United States of America (TSI QUEST<sup>™</sup>, 2018). This monitor enables quick and accurate evaluation of potential heat stress environments by measuring the following: dry bulb (DB) temperature, wet bulb (WB) temperature, globe temperature, wet bulb globe temperature indoors (WBGT<sub>i</sub>) and outdoors (WBGT<sub>o</sub>), relative humidity (RH), and humidex or heat index (HI). DB temperature refers to ambient air temperature, whilst WB temperature refers to air temperature as air passes through a thermometer covered by a wet cloth. Globe temperature indicates radiant heat exposure when exposed to direct sunlight or hot objects in the environment. The DB, WB and globe temperature show data in degrees Celsius (°C). RH represents the amount of water vapor present in the air and is represented as a percentage

of the amount required for saturation to occur at the same temperature. Therefore, the QUESTemp<sup>032/34</sup> represents wet bulb globe temperature (WBGT) data which allows one to estimate the effect of temperature, wind speed, humidity, visible radiation and infrared radiation on humans, in terms of the amount of heat stress experienced, using heat stress exposure tables (TSI QUEST<sup>TM</sup>, 2018).

## **2.10 Exposure limits**

The international threshold limit value (TLV) for effective irradiance is 30 Joules per meter squared ( $\text{J/m}^2$ ) according to the American Conference of Industrial Hygienists (ACGIH) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) which is equivalent to 109  $\text{J/m}^2$  per 8-hour shift using the Commission Internationale de l'Éclairage (CIE) spectrum (Moehrle *et al.*, 2003; ICNIRP, 2010). To prevent retinal and lens damage, the UVA radiant exposure should not be higher than 1  $\text{J/m}^2$  if the daily cumulative exposure is less than seventeen minutes. The UVA irradiance exposure should not be greater than 1 millivolt per centimetre squared ( $\text{mV/cm}^2$ ) for daily cumulative exposure exceeding seventeen minutes (ICNIRP, 2010). Since South Africa does not have an occupational exposure limit for solar UVR, reference will be made to the CIE spectrum (DoL, 1993). However, the ACGIH and ICNIRP apply this TLV in different ways, as explained in Table 3 below (SSAWC, 2016). UVR is radiometrically measured or spectrally weighted. This measured value refers to the CIE erythema reference action spectrum and indicates the ability of the sun to produce erythema (redness) (Lucas *et al.*, 2002). There are two types of erythema dosages: minimal erythema dosage (MED) and standard erythema dosage (SED). MED refers to the erythema radiant exposure producing noticeable redness on previously unexposed skin and depends on factors such as skin type and anatomical area of exposure. Application of MED is limited as this dosage places emphasis on individual skin type. One SED equates to an erythema radiant exposure of 100  $\text{J/m}^2$ , therefore the TLV of 109  $\text{J/m}^2$  corresponds to 1.09 SED and does not depend on skin type. Consequently, this measurement allows for whole-body application in practice (Lucas *et al.*, 2002).

**Table 3:** Differences in TLV application between ACGIH and ICNIRP (SSAWC, 2016).

| ACGIH                                       | ICNIRP                                            |
|---------------------------------------------|---------------------------------------------------|
| Workers                                     | Workers and public                                |
| TWA of 8-hours per day                      | Non-specific – anytime                            |
| Natural and artificial sources of solar UVR | Artificial sources of solar UVR only              |
| Eye and skin exposure                       | Recommended for skin exposure                     |
| Acknowledges melanin content of the skin    | Provides an absolute limit for direct eye contact |

Note: TWA (Time-weighted average), ACGIH (American Conference of Governmental Industrial Hygienists), ICNIRP (International Commission on Non-Ionizing Radiation Protection).

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## CHAPTER 3: ARTICLE

### AUTHOR GUIDELINES

This article will be submitted to *Annals of Work Exposure and Health* and it is written in the format prescribed by the journal.

*Annals of Work Exposure and Health* publishes original research as well as development materials which aid in reducing the risk of ill-health resulting from work. Original research papers are reports of scientific investigations of matters affecting occupational risk, exposures and methods of their assessment. Original research reports may be descriptive, observational, and/or experimental investigations, and can usually be presented as hypothesis-driven research. They should be able to clearly state their aim, define the methods with which evidence is gathered and organized, describe the analytic methods used, and present the results of these analyses in a transparent and interpretable format. The conclusion of the paper must be supported by the data and their analysis.

*Language:* Manuscript must be in English and written in a way which is simple and clear. British or American styles and spelling may be used, but it should be used consistently, and words or phrases which might be unclear in other parts of the world should be avoided or clearly explained.

*Brevity:* The necessary length of a paper depends on the subject, but any submission must be as brief as possible consistent with clarity. The number of words, excluding the abstract, references, tables and figures, must be stated as a message to the Editor at the time of submission. If the length is more than 5000 words, a statement must be included justifying the extra length.

*Title, abstract and keywords:* These are important because most readers find papers by internet search of subjects, not by browsing the journal. Titles should be constructed to succinctly describe the major issue or question examined by the paper and should not assert the research findings as a truth. Recognizable, searchable terms and keywords must be included to enable readers to more effectively find your paper. To optimize the visibility of your paper, make a list of the 10 most likely search terms that your intended readers will use to find your work, and ensure that these appear in your title, abstract and the keywords.

*Authorship:* Persons should only be named as authors if they have made substantial contributions to the conception or design of the work, or the acquisition, analyses or interpretation of data for the work and have assisted with the drafting or revising of the paper for important intellectual content and have final approval of the version to be published and can take responsibility for the accuracy of the work. Other contributions may be recognized by acknowledgement at the end of the submission. All names and affiliations of the authors should be clearly stated at the beginning of the paper.

*Structure of the paper:* Papers should generally conform to the pattern: Introduction, Methods, Results, Discussion, and Conclusion, unless these are clearly inappropriate. A paper must be prefaced by an abstract of the argument and finding, which may also be arranged under the same headings.

*Design and analysis:* The quality of the data and analysis must always be good enough to justify the inferences and conclusions drawn. Particular attention should be given to design of sampling surveys, which should be planned using modern statistical principles, and the treatment of results below the limit of detection.

*Units and symbols:* SI units must be used, though their equivalent in other systems may be given as well.

*Figures:* These include photographs, diagrams and charts. The first submission should include good quality low resolution copies of Figures and may be incorporated into the text or at the end of the manuscript.

*Tables:* Tables should be numbered consecutively and given a suitable caption. As with Figures, it is helpful to incorporate them into the text of the first submission. Footnotes to tables should be provided below the table and should be referred to by the superscript lowercase letters.

*References:* References should only be included which are essential to the development of an argument or hypothesis, or which describe methods for which the original account is too long to be reproduced. References in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones *et al.* (1995) if there are more than two authors, and they should be incorporated naturally into the text. For example:

Jones and Brown (1995) and Hospath *et al.* (2006) observed total breakdown of control..., or  
Total breakdown of control has sometimes been observed (Jones and Brown, 1995; Hospath *et al.*, 2006).

At the end of the paper, references should be listed in alphabetical order by names of the first author, using the Harvard Style of abbreviation and punctuation. ISBNs should be given for books and other publications where appropriate. Material unobtainable by readers should not be cited. Personal Communications, if essential, should be cited in the text (e.g., Professor O.H. Poobah, Institute for Dusty Sciences). Internet material can be referred to if it is likely to be permanently available; the date on which it was last accessed should be given.

Examples:

Simpson AT, Groves JA, Unwin J, Piney M. (2000) Mineral oil metal working fluids (MWFs)—Development of practical criteria for mist sampling. *Ann Occup Hyg*; 44:165–72.

Vincent JH. (1989) *Aerosol sampling: science and practice*. Chichester, UK: John Wiley. ISBN 0 471 92175 0.

Swift DL, Cheng Y-S, Su Y-F, Yeh H-C. (1994) Ultrafine aerosol deposition in the human nasal and oral passages. In Dodgson J, McCallum RI, editors. *Inhales Particles VII*. Oxford: Elsevier Science. p. 77–81. ISBN 0 08 040841 9 H.

British Standards Institution. (1986). BS 6691: 1986. Fume from welding and allied processes. Part1. Guide to methods for sampling and analysis of particulate matter. London: British Standards Institution.

Morse SS. (1995) Factors in the emergence of infectious diseases. *Emerg Infet Dis* [serial online\ 1995 Jan–Mar; 1(1). Available from: URL: <http://www.cdc.gov/ncidod/EID/eid.htm> (accessed 25 Oct 2010).

*Supplementary materials:* supporting material is not essential for argument of the paper, but would nevertheless benefit the reader, can be submitted for online edition only.

## **Exposure of car guards to solar ultraviolet radiation during summer and winter**

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*Keywords:* Solar ultraviolet radiation, personal exposure, car guards, summer, winter, heat stress, electronic dosimeters and QUESTemp<sup>o</sup>32/34.

6432 words

### 3.1 Abstract

**Introduction:** Outdoor workers such as car guards are at an increased risk of excessive exposure to solar UVR due to long hours working in the absence of a shade structure and personal protective equipment. Cumulative exposure increases the risk of developing adverse health effects such as skin cancer, a Group 1 carcinogen, caused by the sun. The aim of this study was to quantify personal solar ultraviolet radiation exposure of car guards during summer and winter.

**Methods:** Car guards' upper arm exposure to solar UVR was measured at the shopping centre for 10 days during summer (20 February 2019 – 05 March 2019) and winter (22 July 2019 – 02 August 2019) respectively by means of Genesis-UV personal electronic dosimeters. The Genesis-UV dosimeter was placed on the upper arm of the participant using an adjustable strap. Results from these measurements were used to estimate solar UVR exposure on various anatomical areas. In addition, hand-held UV monitors were used to determine the levels of ambient solar UVR reaching a flat, horizontal surface and heat stress levels were also determined during the sampling period by means of the QUESTemp<sup>o</sup>32/34. The QUESTemp<sup>o</sup>32/34 was used to evaluate environmental conditions such as temperature and relative humidity influencing the intensity of solar UVR received by workers.

**Results:** The average seasonal exposure of car guards to solar UVR was 11.50 SED during summer and 5.47 SED during winter. Exposure as a percentage of ambient UVR during summer was 30.79%, whilst that of winter was 26.61%. The exposure of car guards on the upper arm was below that of other anatomical areas, even though values were in excess of the threshold limit value (TLV). Heat stress measurements obtained during summer indicated a WBGT<sub>o</sub> ranging between 22.60 – 30.94, and that of winter ranged between 8.32 – 20.32.

**Conclusion:** The high exposure of car guards to solar UVR is a concern because while being independent contractors, it is difficult for them to implement the necessary protective measures. The security industry together with companies manufacturing sunscreens and protective clothing (sun hats and long-sleeved shirts) should form a collaboration with each other promoting the effective use of protective measures among car guards.

**Keywords:** Solar ultraviolet radiation, personal exposure, car guards, summer, winter, heat stress, electronic dosimeters and QUESTemp<sup>o</sup>32/34.

### 3.2 Introduction

Solar ultraviolet radiation (UVR) exposure plays a major role in the daily activities of most individuals, either during work or leisure activities (Makgabutlane and Wright, 2015). The benefits of moderate exposure to solar UVR include vitamin D production which is required for skeletal development and protection against certain diseases (US FDA, 2017; Lucas *et al.*, 2016; WHO, 2019a). The risks associated with excessive exposure on the other hand, include sunburn, photoaging, skin cancer, ocular cataracts, pterygium and photo-kerato-conjunctivitis (Lucas *et al.*, 2016). Studies have shown that skin cancer is the most prominent adverse effect in which solar UVR exposure plays a role as it is a confirmed Group I carcinogen (IARC, 2010; Makgabutlane and Wright, 2015; Craythorne and Al-Niami, 2017).

Skin cancer is divided into melanoma and non-melanoma skin cancer (NMSC). NMSC is referred to as keratinocytic cancer. Melanoma skin cancer is largely a result of intermittent UVR exposure and mainly affects the population with light skin types because of the lower melanin concentration when compared to those with darker skin types (Narayanan *et al.*, 2010; American Cancer Society, 2012; Craythorne and Al-Niami, 2017; WHO, 2019a). Keratinocytic cancer occurs over time (cumulative exposure) in areas frequently exposed to the sun and is subdivided into basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). This type of cancer metastasizes slower than melanoma skin cancer and can be removed surgically before becoming life-threatening (WHO, 2019a). Thus, a balance needs to be established between the negative and positive effects of exposure to solar ultraviolet radiation.

South African outdoor workers are exposed to high levels of solar UVR because of the country's high altitude and low latitude, together with clear skies and average temperatures of 22 °C (Makgabutlane and Wright, 2015). The amount of UVB radiation reaching the earth's surface is largely influenced by the ozone levels in the stratosphere. Increases in ozone depletion affect the solar spectrum causing an increase in ultraviolet B (UVB) reaching the earth (Bais *et al.*, 2015). Such findings exist for South Africa too where increased levels of solar UVB radiation reaching the earth's surface were found during spring and summer because of decreased levels of the stratospheric ozone (du Preez *et al.*, 2018).

Several outdoor occupations require prolonged hours spent outdoors in the absence of shade, thereby increasing the risk of developing negative health effects, especially keratinocytic cancers. A previous South African study showed that a worker's exposure was 84% of the ambient solar UVR prompting the necessity for long-term solar UVR exposure measurements particularly since solar UVR is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) (IARC, 2012; Makgabutlane and Wright 2015).

Elsewhere, solar UVR exposure measurement studies were conducted in larger industries such as farming and construction with very few having focused on distinct industries such as car guarding (IFA, 2015).

Car guarding, a phenomenon unique to South Africa, provides a security service to individuals by safeguarding their cars in parking areas of shopping centres all over the country. As independent contractors in the informal sector, it is difficult for car guards to implement the necessary protective measures. Additionally, the nature of the service offered by car guards does not allow them to negotiate their working hours. Choice of location where shade may be available and taking a break is done at the risk of losing the monetary gratitude from car owners. Furthermore, workers in informal sectors do not view solar UVR exposure as a serious occupational hazard and are less likely to adhere to sun protective measures likely due to lack of training (Carey *et al.*, 2014). Similarly, Nkogatse *et al.* (2019) found that car guards had never received any form of training or education regarding sun safety. Knowledge regarding adverse health effects associated with exposure was limited to skin cancer and frequently used protective measures consisted of long pants and sun hats, while sunscreen was applied by 30% of car guards (Nkogatse *et al.*, 2019).

Exposure measurements of outdoor workers are required to quantify the levels and risk of exposure which allows for the recommendation as well as evaluation of the effectiveness of protective measures. To date, two studies evaluated the exposure of car guards to solar UVR during spring in South Africa. The first study was a pilot involving one participant over a single day and the second study included 10 participants' exposure measured over several days. The findings from both studies pointed to significantly high exposure levels indicating the likelihood of overexposure occurring during the summer months (Wright, 2015; Nkogatse *et al.*, 2019).

The main aim of this study was to quantify personal solar UVR exposure of car guards during summer and winter using electronic dosimeters. Results obtained from this study were compared to the threshold limit value (TLV) to determine whether exposure was above or below the required TLV of 109 Joules per meter squared ( $\text{J/m}^2$ ) (1.09 SED) per 8-hour shift using the Commission Internationale de l'Éclairage (CIE) spectrum (Moehrle *et al.*, 2003; ICNIRP, 2010). Temperature, relative humidity and heat stress measurements were also made to fully understand the outdoor environment which contributes to the solar UVR experienced by workers i.e. increased temperatures result in increased damage (US FDA, 2017). This study together with that conducted by Makgabutlane and Wright (2015), Wright (2015) and Nkogatse *et al.* (2019) may be used as a baseline to encourage the implementation of measures to protect outdoor workers against excess solar UVR exposure.

### **3.3 Materials and methods**

#### **3.3.1 Study area and design**

This quantitative study was performed at a shopping centre in Potchefstroom (North West Province, South Africa). The North West Province, known for its sunshine and relatively clear skies almost all year-round, and is adjacent to the southern boundary of the Kalahari Desert. Potchefstroom is the fourth biggest town in the North West Province and is situated at an altitude of 1378 metres (m) above sea level. Thus, high levels of solar UVR reach the earth's surface in this town.

#### **3.3.2 Study population**

Car guards work in parking lots where the absence of sufficient shade may result in excessive solar UVR exposure. A working day consists of a morning shift from 09:00 am to 03:00 pm and a night shift from 03:00 pm to 11:00 pm. A total of 15 car guards, men and woman of different ethnic groups, provided a security service during each work shift. Car guards working from 9:00 am up to 03:00 pm were eligible to participate in this study because the peak exposure period being 10:00 am to 02:00 pm fell within this time. In addition, participants had to be 18 years old and above as well as working a minimum of 5 hours during the day shift for at least 4 days per week of sampling to be included in the study. Age was an important inclusion criterion since the car guards were required to give written informed consent on the form provided (see Annexure B), before they could take part in the study to satisfy the terms of approval by the Human Research Ethics Committee (HREC) of North-West University, Potchefstroom Campus (Ethics number NWU-00133-18-A1). A total of eight car guards willingly participated in this study during summer and six car guards participated during winter. These participants consisted out of both males and females of different ethnicity.

#### **3.3.3 Sampling technique**

This study comprised the following measurements: personal UVR exposure using Genesis-UV dosimeters, ambient UVR using hand-held UV monitors; and heat stress measurements such as temperature and relative humidity using the QUESTemp<sup>®</sup>32/34. The measurements were conducted from Monday to Friday over a period of 10 days in February/March and July/August to represent exposure patterns for summer and winter respectively on the same participants. However, participants seven and eight did not participate during the winter measurement period.

### 3.3.3.1 Genesis-UV dosimeter

The Genesis-UV dosimeters, manufactured in Germany, measure both ultraviolet A (UVA) and ultraviolet B (UVB) radiation (Wittlich, 2015). A tablet PC was used to set up the dosimeters according to the required period (date and time) for measurements to take place (e.g. 20/02/2019 – 05/03/2019 09:00 am – 03:00 pm). This information was exported from the tablet to the Genesis-UV dosimeter and the file was saved according to study requirements (e.g. Feb/Mar – summer measurements). The final step was to enable the logger so that the Genesis-UV dosimeter was ready for measurements. To set the other dosimeters according to the required measuring period, old data were deleted (delete logger), time zone was checked and written into device, after which data were imported from the saved file. At the end of the sampling period, data were uploaded onto the Genesis-UV database in Germany, and calculations were conducted by the Deutsche Gesetzliche Unfallversicherung (DGUV) team and sent back to the researcher at Potchefstroom Campus of North-West University in the form of Joules per metre squared ( $\text{J/m}^2$ ) which was then converted into standard erythema dose (SED).

$$\text{Equation 1: } SED = \frac{\text{J/m}^2}{100}$$

Where:

SED = Standard erythema dose

$\text{J/m}^2$  = Joules per metre squared

### 3.3.3.2 Hand-held UV monitor

The hand-held UV monitor used in this study was manufactured by IDT Technology Limited, Hung Hom, Kowloon, Hong Kong for Oregon Scientific. The battery-operated monitor recorded data in the form of an ultraviolet index (UV) value which indicated the level of risk likely to occur with exposure (WHO, 2019a). To obtain the UV index, the UV monitor was placed in the sun for  $\pm 5$ -minutes, ensuring sensor stabilization. Thereafter, hourly UV index values were obtained by pressing the button on the side. The sensor measured for 4 seconds before producing a UV value.

### 3.3.3.3 Heat stress monitor and measurement procedure

The QUESTemp<sup>®</sup>32/34 (QUEST Technologies, Oconomowoc, WI, USA) was used to determine heat stress levels daily during the sampling period. The existing battery was tested

and where necessary replaced with a new 9V battery. With the wet bulb wick checked for cleanliness, the reservoir was filled with distilled water. This instrument was placed at a height of 1.1 m (as stated in the manual) on a tripod (as indicated in Figure 1) and switched on (TSI QUEST™, 2018). Sensors were allowed a minimum of ten minutes to stabilize with the environment after which hourly measurements were obtained for each day. Measurements were noted down and daily outdoor wet bulb globe temperature (WBGT<sub>o</sub>) results were calculated using equation 2 below. The average WBGT results were calculated using equation 3.



**Figure 1:** A photo showing the setup of the QUESTemp<sup>®</sup>32/34 at the study area.

$$\text{Equation 2: } \text{WBGT}_o = 0.7\text{T}_{\text{nwb}} + 0.2\text{T}_g + 0.1\text{T}_{\text{db}}$$

Where:

WBGT<sub>o</sub> = Wet bulb globe temperature outdoors

T<sub>nwb</sub> = natural wet bulb temperature

T<sub>g</sub> = globe temperature

T<sub>db</sub> = dry bulb temperature

Equation 3:

$$WBGT_{ave} = \frac{(WBGT1)(t1)+(WBGT2)(t2)+(WBGT3)(t3)+(WBGT4)(t4)+(WBGT5)(t5)+(WBGT6)(t6)+(WBGT7)(t7)}{t1+t2+t3+t4+t5+t6+t7}$$

Where:

$WBGT_{ave}$  = Average wet bulb globe temperature

Interpretation of the  $WBGT_o$  measurements is made with the American Conference of Governmental Industrial Hygienists (ACGIHs) threshold limit value (TLV) of 30 for 70-100% of light work. The threshold temperatures of ACGIH indicate the level of risk likely to occur and are as follows: WBGT less than 29.3 indicates low risk, between 29.3 and 32.1 indicate moderate risk, and WBGT higher than 32.1 indicates high risk. These threshold temperatures were used as a guideline to indicate the level of risk likely to occur during the sampling period in summer and winter (Yi and Chan, 2017).

### 3.3.4 Method used for personal solar UVR exposure measurements

The participants received Genesis-UV dosimeters and an adjustable strap at the start of the shift. In privacy, the dosimeters were placed on the upper arm of choice, as demonstrated to the participants prior to start of measurements (See Figure 2). These dosimeters were worn for the full day shift and collected at the end of each shift for safe keeping, charging whenever necessary, as well as for retrieval of data.



**Figure 2:** Figure showing the GENESIS-UV dosimeter placement on upper arm (IFA, 2015).

### 3.3.5 Method used to determine exposure as a percentage of ambient UVR

The hand-held UV monitor represents data in the form of a UV index. However, this does not represent exposure in terms of standard erythemal dose (SED), but rather indicates the level of risk likely to occur. SED represents the levels of solar UVR exposure received by an individual, irrespective of skin colour. To obtain an SED value, equation 4 was used as a reference for obtaining the minimal erythemal dose (MED) as indicated in equation 5 where the UV index was converted into MED (Cadet *et al.*, 2017). This MED value was then multiplied by 2.1 to represent data as an SED value ( $SED = MED \times 210/100$ ). Once values were converted into an SED, equation 6 was used to determine exposure as a percentage of ambient UVR (Nkogatse *et al.*, 2019).

$$\text{Equation 4: } UV \text{ index} = MED \times \frac{210 \times 40}{3600}$$

$$\text{Equation 5: } MED = UV \text{ index} \div \frac{210 \times 40}{3600}$$

$$\text{Equation 6: } \text{Exposure as a percentage of ambient UVR} = \frac{\text{Personal exposure (SED)}}{\text{Ambient exposure (SED)}} \times 100$$

### 3.3.6 Method used to determine anatomical areas of exposure

To determine the exposure of different anatomical areas to solar UVR, data had to be extrapolated from the measured upper arm values by using equation 7. The equation used for exposure as a percentage of ambient UVR (EPA) for the vertex, forehead, nose, cheek, nape, hands and shoulders were obtained from Wright *et al.* (2004).

$$\text{Equation 7: } TDE = \left( DE \text{ upper arm} \times \frac{100}{45} \right) \times EPA \text{ of anatomical site}$$

Where:

TDE = Total daily exposure

DE = Daily exposure of the measured anatomical position (upper arm).

100% = Exposure of the vertex as a percentage of the ambient solar UVR.

45% = Upper arm exposure as a percentage of the ambient UVR.

EPA = Exposure as a percentage of ambient UVR for the anatomical site in question

### **3.3.7 Statistical analysis**

The analysis and interpretation of data obtained from the dosimeters were controlled and verified by the statistical consultant. The statistical package, SPSS IBM Corp (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp, 2017) was used for data analysis and Graph Pad Prism 8 (2019 Graph Pad Software Inc.) was used for the graphical representation of dosimeter data. A p-value of  $\leq 0.05$  was considered statistically significant. Descriptive statistics (mean and standard deviation) were used to calculate daily exposure levels as well as the seasonal data sets of the electronic dosimeters. Due to a small sampling group, testing for normality was not practicable, thus the Paired t-test and Wilcoxon rank sum test were conducted to determine whether the results differed significantly between summer and winter and by anatomical area.

## **3.4 Results**

### **Environmental conditions**

The shopping centre chosen for this study consisted of tall brick buildings, painted corrugated iron roofing, asphalt concrete covering the ground surface and a large open area with small trees. Clear skies were observed throughout the summer sampling period except for the last day (05-03-2019) when there was cloud cover. The winter sampling period consisted of a few days of clear skies and a few days of cloud cover. Information regarding weather conditions and the measure of cloud cover (okta) are represented in Table 1. According to SSERC (2012), okta represents the amount of clouds covering the sky, and is measured based on an eight-point scale. For example, if the measure of cloud cover is 3 oktas, that means that  $\frac{3}{8}$  of the sky is covered by clouds.

**Table 1:** Daily weather forecast and measure of cloud cover in okta obtained from South African Weather Services (SAWS)

| Summer     |                |      | Winter     |                |      |
|------------|----------------|------|------------|----------------|------|
| Date       | Sky conditions | Okta | Date       | Sky conditions | Okta |
| 20/02/2019 | Clear skies    | 0    | 22/07/2019 | Partly cloudy  | 3-4  |
| 21/02/2019 | Clear skies    | 0    | 23/07/2019 | Overcast       | 8    |
| 22/02/2019 | Sunny          | 2    | 24/07/2019 | Partly cloudy  | 3-4  |
| 25/02/2019 | Clear skies    | 0    | 25/07/2019 | Sunny          | 2    |
| 26/02/2019 | Sunny          | 2    | 26/07/2019 | Sunny          | 2    |
| 27/02/2019 | Clear skies    | 0    | 29/07/2019 | Sunny          | 2    |
| 28/02/2019 | Clear skies    | 0    | 30/07/2019 | Partly cloudy  | 3-4  |
| 01/03/2019 | Clear skies    | 0    | 31/07/2019 | Overcast       | 8    |
| 04/03/2019 | Clear skies    | 0    | 01/08/2019 | Partly cloudy  | 3-4  |
| 05/03/2019 | Overcast       | 8    | 02/08/2019 | Sunny          | 2    |

### 3.4.1 Solar ultraviolet exposure measurements

#### 3.4.1.1 Personal exposure measurements

Average daily exposures for winter remained below the threshold limit value (TLV) of 1.09 SED with the minimum being 0.07 SED and maximum of 1.03 SED (Figure 3). On specific days during summer, however, the TLV was exceeded with a minimum of 0.05 SED and a maximum of 1.77 SED. Seasonal differences in exposure were statistically significant ( $p < 0.0001$ ). Furthermore, variations in average exposure were observed among the car guards, where the mean and standard deviation (SD) for both seasons were as follows: summer =  $0.96 \pm 0.34$ ; winter =  $0.33 \pm 0.27$ .

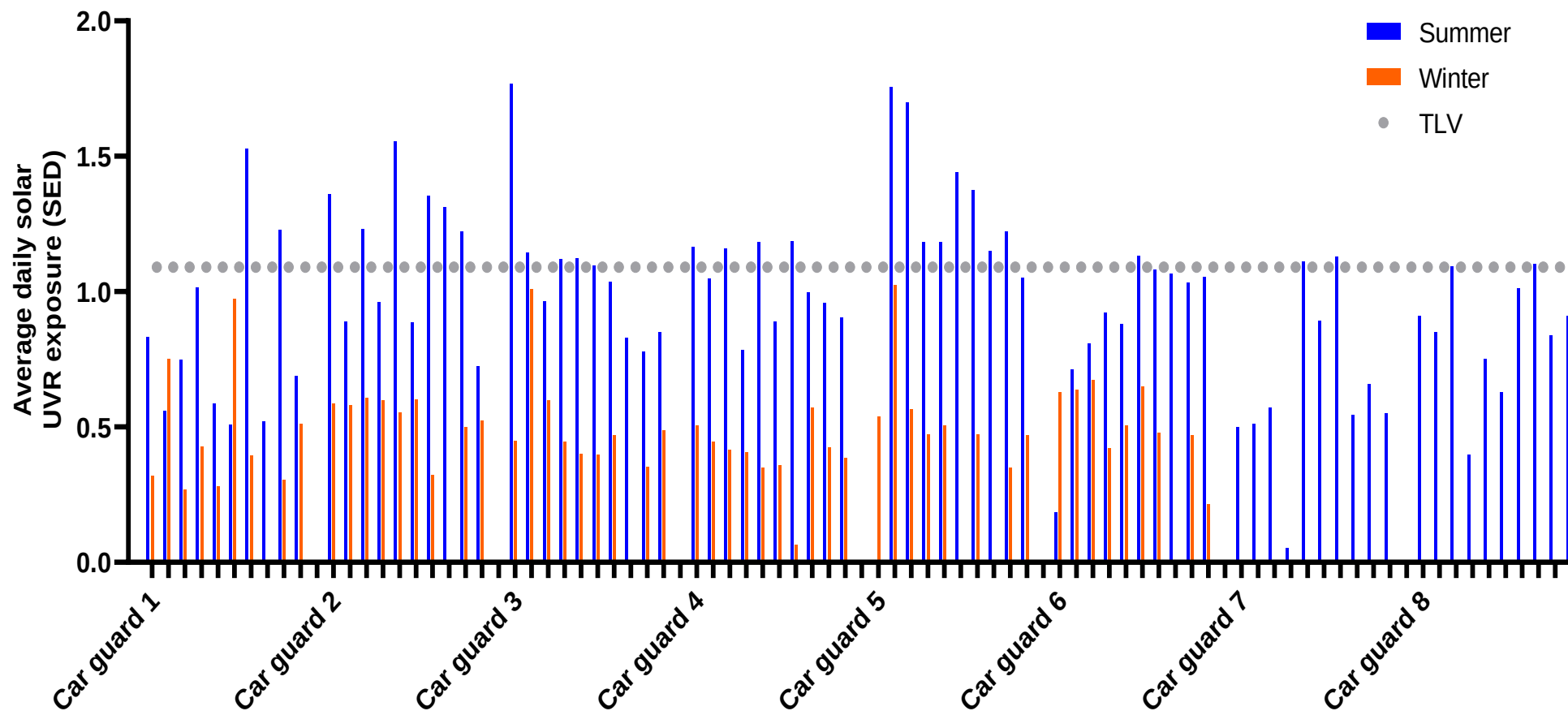


**Figure 3:** Average daily exposure of each car guard to solar UVR per day during 10 days in summer and winter against the threshold limit value (TLV). (Blank columns represent missing data).

Figure 4 represents personal solar UVR exposure over time during summer and winter, thus indicating the times where exposure values increased, reached a peak and then decreased again. Minimum exposure values for summer occurred at 09:00 am (0.49 SED) and 02:30 pm (0.46 SED), while maximum exposure values occurred at 12:30 pm (1.21 SED), respectively. Similarly, minimum winter values occurred at 09:00 am (0.18 SED) and 02:30 pm (0.23 SED), while maximum exposure values occurred at 11:30 am (0.68 SED), respectively. The mean and SD for summer was  $0.96 \pm 0.28$  SED, and that of winter was  $0.50 \pm 0.18$  SED.

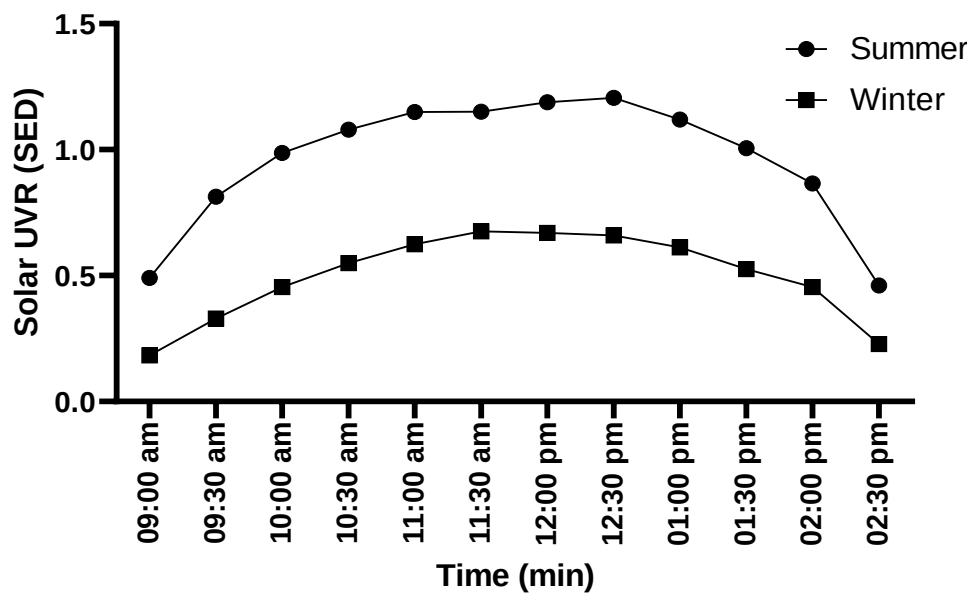


**Figure 4:** Average personal solar UVR exposure over time during summer and winter.

#### 3.4.1.2 Exposure as a percentage of ambient solar UVR

The average exposure of each car guard as a percentage of ambient UVR measured on the upper arm was 30.79% during summer, which was higher than the 26.61% received in winter (Figure 5). During summer, exposure of car guards 2, 3, 4 and 5 exceeded the average exposure as a percentage of ambient UVR, with the highest being that of car guard 5 (38.49%). The graphical representation for winter, on the other hand, shows exposure of car guards 2, 3, 5 and 6 having exceeded the average exposure as a percentage of ambient UVR, with the highest reaching 29.42% (car guard 5).

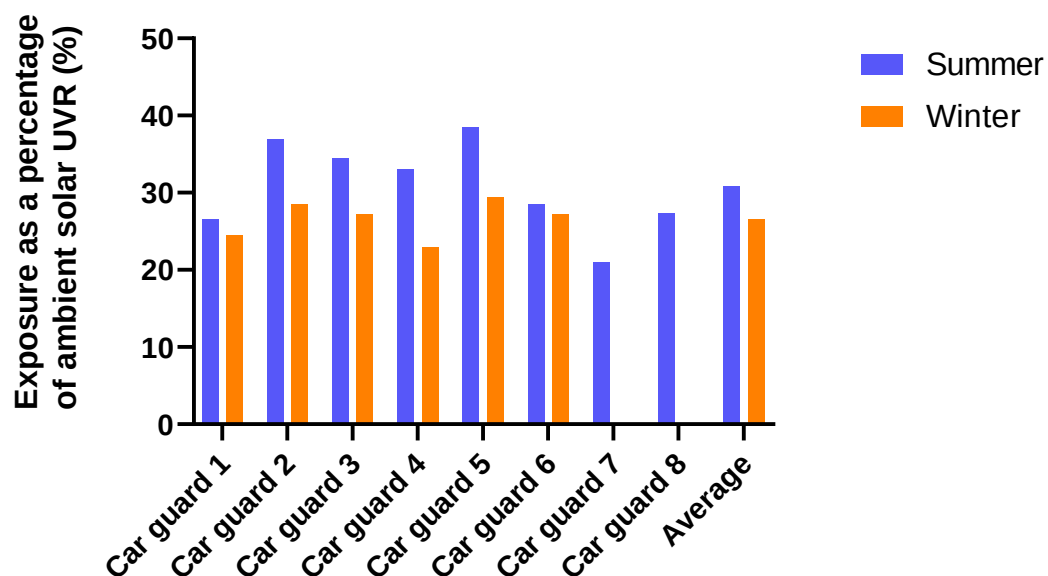


**Figure 5:** The seasonal exposure of car guards to solar UVR as a percentage of ambient UVR measured on the upper arm. (Blank columns represent missing data).

#### 3.4.1.3 Estimated exposure on different anatomical areas

The estimated seasonal exposure to solar UVR on different anatomical areas is presented in Figures 6a and 4b. Figure 7 gives an overall representation of the average levels of solar UVR that different anatomical areas received during summer and winter. The average level of solar UVR received on the upper arm of each car guard during summer (11.5%) and winter (5.99%) was lower than the levels of solar UVR calculated for different anatomical areas such as the hands and shoulders. The vertex received the highest dose of solar UVR with the average level of exposure during summer being 25.55% and that of winter being 13.31%.

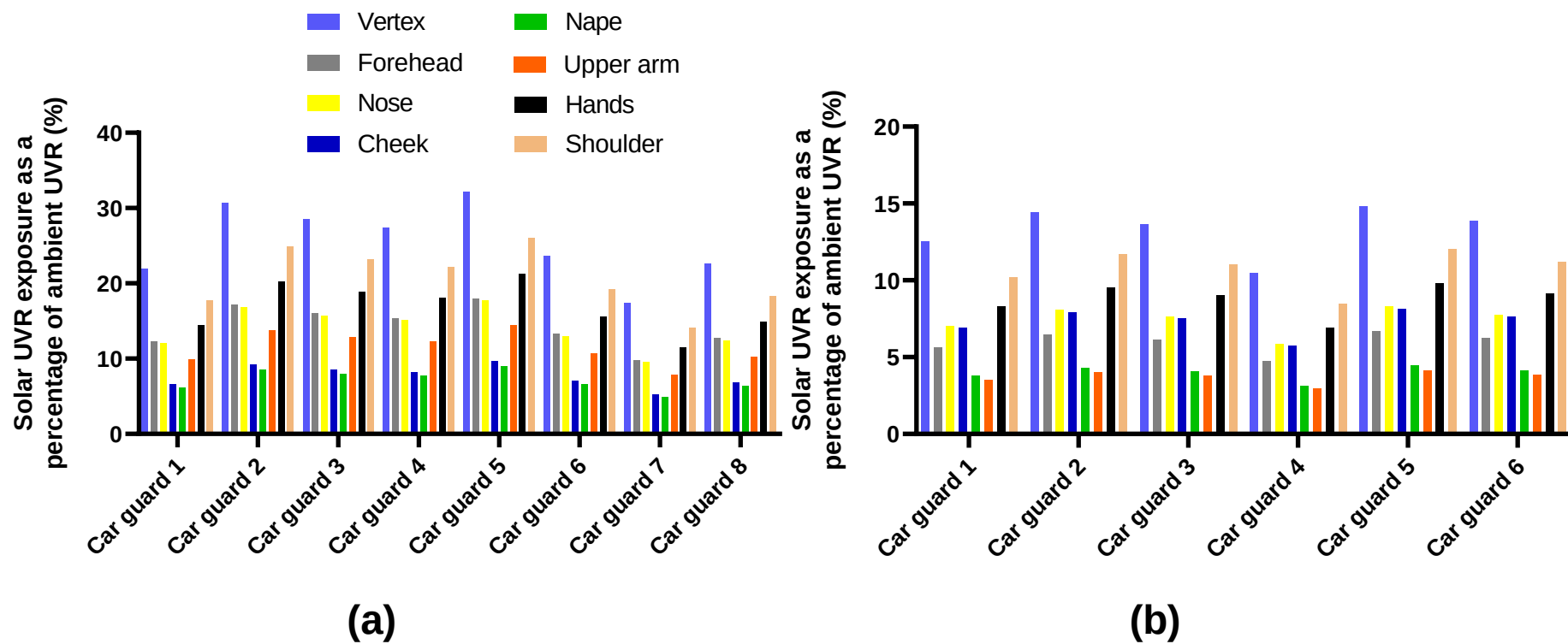


**Figure 6:** The estimated exposure of car guards to solar UVR on different anatomical areas as percentage of the ambient during (a) summer and (b) winter.

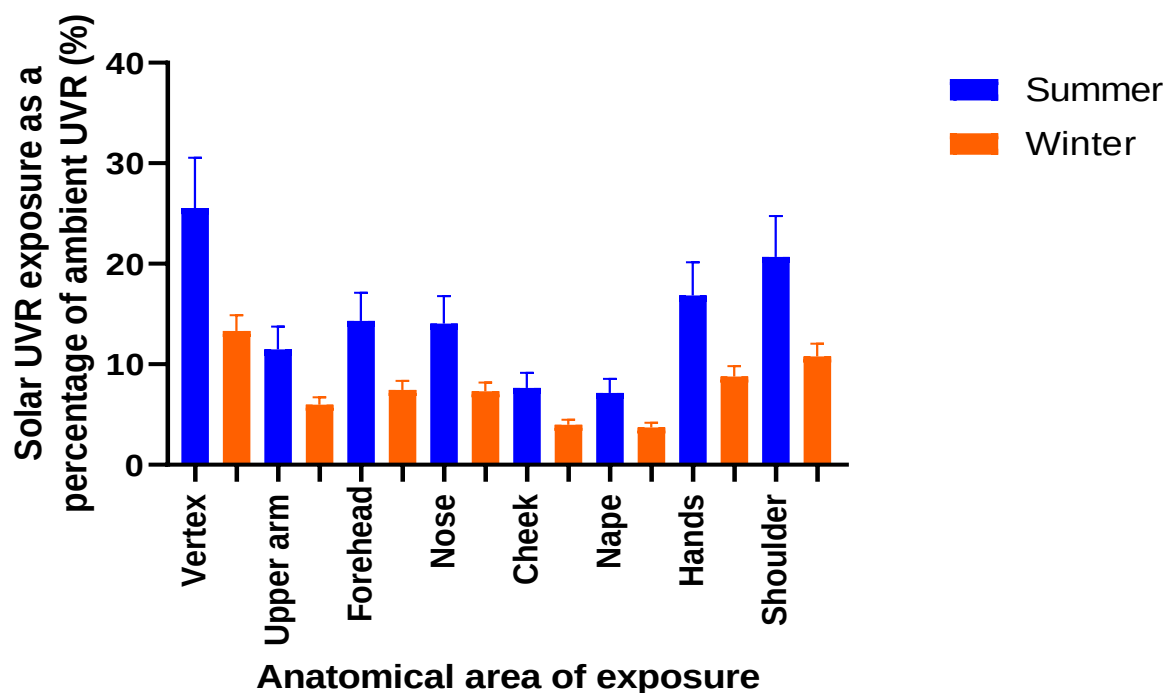


**Figure 7:** Average percentage of seasonal solar UVR exposure on different anatomical areas.

### 3.4.2 Ambient conditions and heat stress measurements

The seasonal hourly outdoor wet bulb globe temperature (WBGT<sub>o</sub>) measurements indicate that the summer WBGT<sub>o</sub> ranged between 22.60 – 30.94, while those for winter ranged between 8.32 – 20.32 (Table 2 and Figure 8). Average dry bulb (DB) temperature, relative humidity (RH) and ultraviolet (UV) index during both seasons are presented in Figure 9a, while the minimum, maximum and median values are given in Figure 9b. The minimum value for DB temperature, RH and UV index during summer were 25°C, 13.71% and 5; while the maximum values were 35°C, 35.29% and 6 respectively. The minimum values obtained for winter in the same order were 12°C, 10.14% and 3, while the maximum values were 25°C, 37.86% and 4. The differences in DB, RH and UV index for summer and winter were statistically significant ( $p < 0.0001$ ).

**Table 2:** Daily WBGT<sub>o</sub> conditions during summer (20 February 2019 – 05 March 2019) and winter (22 July 2019 – 02 August 2019).

|               | Summer           |             | Winter           |             |
|---------------|------------------|-------------|------------------|-------------|
| Time          | Mean $\pm$ SD    | Range       | Mean $\pm$ SD    | Range       |
| 08:00 – 09:00 | 24.39 $\pm$ 1.32 | 26.53-22.6  | 10.99 $\pm$ 1.55 | 14.25-8.32  |
| 09:00 – 10:00 | 25.13 $\pm$ 1.41 | 26.97-22.87 | 12.83 $\pm$ 1.73 | 15.78-10.57 |
| 10:00 – 11:00 | 26.52 $\pm$ 1.51 | 30.2-24.27  | 15.52 $\pm$ 2.08 | 18.13-11.55 |
| 11:00 – 12:00 | 26.88 $\pm$ 0.93 | 28.06-25.7  | 16.01 $\pm$ 1.72 | 18.8-13.03  |
| 12:00 – 13:00 | 27.60 $\pm$ 1.49 | 30.57-25.91 | 17.14 $\pm$ 1.79 | 19.02-12.82 |
| 13:00 – 14:00 | 27.54 $\pm$ 1.55 | 30.94-25.61 | 16.59 $\pm$ 1.49 | 18.3-13.51  |
| 14:00 – 15:00 | 26.78 $\pm$ 1.89 | 29.34-23.54 | 17.48 $\pm$ 1.67 | 20.32-14.13 |

Notes: WBGT<sub>o</sub> (Wet bulb globe temperature outdoors), SD (standard deviation).

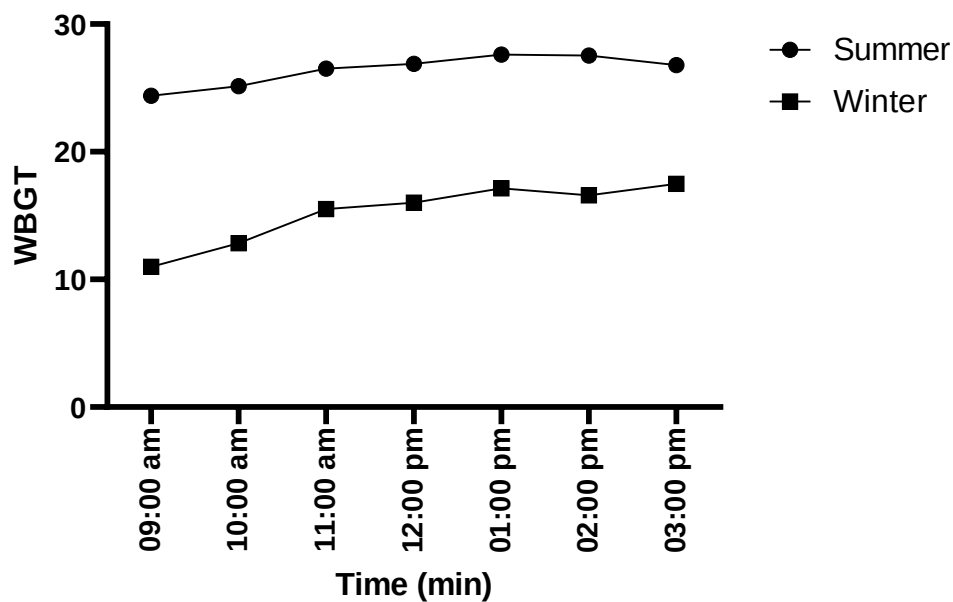


**Figure 8:** Average WBGT over time during summer and winter.

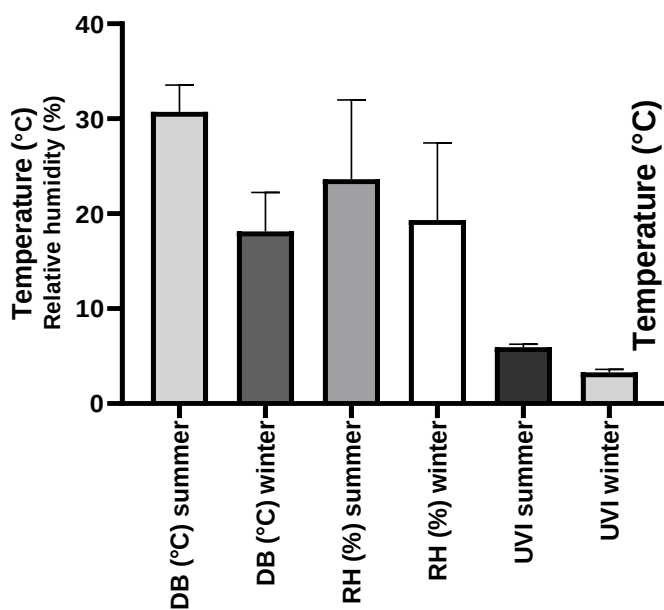


**Figure 9a:** Average daily dry bulb (DB) temperature (°C), relative humidity (RH %), and ultraviolet index (UVI) for summer and winter.

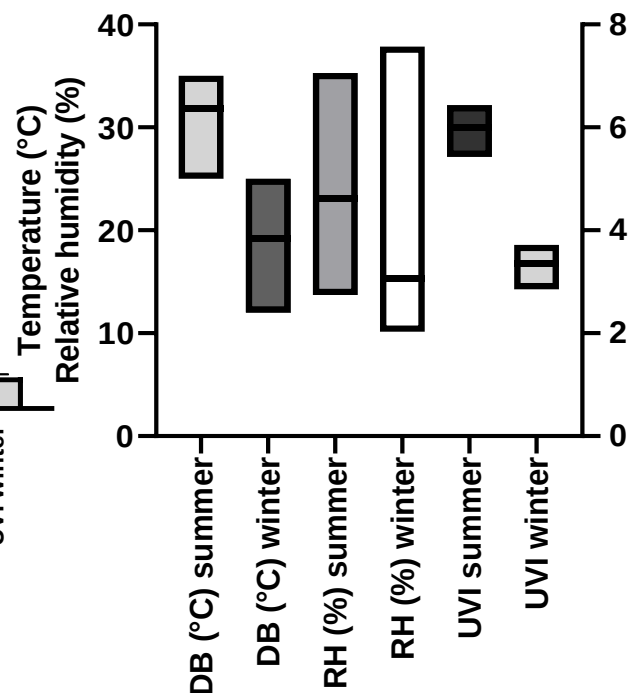


**Figure 9b:** Minimum, maximum and median dry bulb (DB) temperature (°C), relative humidity (RH %), and ultraviolet index (UVI) for summer and winter.

### 3.5 Discussion

The main focus of this study was to quantify the levels of solar UVR which car guards are exposed to during summer and winter. Different areas of the body received different levels of solar UVR, therefore determining exposure on different anatomical areas provides a better understanding regarding areas receiving high levels of exposure, making it possible to recommend the most suitable protective measures reducing exposure. The measurements were accompanied by heat stress measurements which provided information regarding environmental conditions such as temperature (dry bulb °C) and relative humidity (%).

Personal exposure to solar UVR can be influenced by factors such as position of the sun, time of day, season, surface reflection, exposure duration, skin type and work practices (ICNIRP, 2010; Gordon, 2013; Makgabutlane and Wright, 2015; US FDA, 2017; Harris, 2018; Modenese *et al.*, 2018; Nkogatse *et al.*, 2019).

As represented in Figure 3, the different factors explain the differences observed in the average daily exposure of car guards among the individual participants as well as between summer and winter. More specifically, the average daily exposure remained below the TLV during winter, but during summer, average daily exposure of some car guards exceeded the TLV. Summer exposure levels were higher than winter exposure levels. This can be explained by differences in the sun's intensity during summer and winter, work practices and individual behaviour of car guards (Wright *et al.*, 2012; Makgabutlane and Wright, 2015; Zink *et al.*, 2017; Nkogatse *et al.*, 2019). The intensity of solar UVR reaching the earth's surface is dependent on the solar zenith angle (SZA) referring to the tilting ability of the sun at an angle (Makgabutlane and Wright, 2015). As the earth rotates at an angle of 23.5°, one hemisphere faces the sun more than the other hemisphere. When this happens, the hemisphere facing towards the sun will experience a higher solar UVR intensity, thus increasing exposure (Harris, 2018). Therefore, the maximum average solar UVR received by a car guard (Figure 3) during summer was 1.77 SED, while the minimum average solar UVR was 0.05 SED. In contrast, the maximum average solar UVR received by a car guard (Figure 3) during winter was 1.03 SED, while the minimum average solar UVR was 0.07 SED. Findings from this study are similar to those obtained by Makgabutlane and Wright (2015) which indicated that a decrease in the SZA was associated with an increase in solar UVR during the summer months. A similar pattern was also found in a study conducted on Danish workers in various outdoor occupational settings such as roofers, road workers and construction workers (Grandhal *et al.* 2018). The study findings are also consistent with those obtained by Moehrle *et al.* (2003) where exposure of German outdoor workers was found to be high during summer months.

Another factor that plays a role in the amount of solar UVR that car guards receive, is the time of day when exposure occurred. Peak exposure (Figure 4) for summer occurred between 12:00 pm and 12:30 pm and was 1.21 SED, while peak exposure of 0.68 SED for winter occurred between 11:30 am and 12:00 pm. For summer, peak exposure exceeded the TLV, however, in winter it remained below the TLV. ICNIRP (2010) and Modenese *et al.* (2018) found that 75% of exposure occurs between 09:00 am and 03:00 pm. The working hours of the car guards that participated in this study closely matched the time of day when maximum exposure occurs. Exposure increased from 09:00 am and then started decreasing from 01:00 pm (Figure 4). This indicates that car guards are susceptible to experiencing high levels of solar UVR throughout their work shift, which in turn increases their risks of adverse health effects associated with exposure.

Cloud cover either attenuates or enhances solar UVR exposure (ICNIRP, 2010; Makgabutlane and Wright, 2015; Modenese *et al.* 2018). On the last day of the summer measurement period,

cloud cover was observed (Table 1). However, the total daily exposure (6.74 SED) of all the car guards exceeded the TLV on that cloudy day. The average daily exposure of all car guards for nine days during summer varied between 0.97 SED (minimum) and 1.46 SED (maximum), while that of the last day when cloud cover was observed, was 1.01 SED. The average exposure of car guards to solar UVR on days with clear skies did not differ greatly from the day when cloud cover was observed, as can be seen from Figure 3 where SED recorded were between the minimum and maximum exposure values reported for the sampling period. However, the average exposure when cloud cover was observed was lower than the days when no cloud cover was observed. The phenomenon may be attributed to cloud cover playing a role in attenuating solar UVR, thereby redistributing solar UVR to the horizon reducing exposure on the skin. However, the increasing exposure to the eyes due to the scattering of the UV radiation and reflection of light (UV radiation) from different surfaces present in the study area cannot be ignored (ICNIRP, 2010; Sasaki *et al.*, 2011; Gao *et al.*, 2012; Makgabutlane and Wright, 2015).

A study conducted by Nkogatse *et al.* (2019) found the total daily exposure of car guards during spring to be lower than the TLV of 1.09 SED, with maximum exposure reaching 0.63 SED, while that conducted by Linde *et al.* (2015) found farmworker exposure to be in excess of the TLV (maximum daily exposure = 1.62 SED). This study's findings are consistent with those conducted by Nkogatse *et al.* (2019) since the same sampling population was used to identify car guard exposure in different seasons. Even though findings are consistent with that of Nkogatse *et al.* (2019), this current study did not make use of questionnaires evaluating knowledge, behaviour and attitudes. Furthermore, findings from different studies vary because of differences in seasons measured, instruments used, locations measured (different altitudes and latitudes) and different work categories measured, thus making it difficult to compare findings. All studies, however, provide a baseline indicating the likelihood of excess exposure to solar UVR occurring in outdoor workers.

The seasonal exposure of each car guard as a percentage of ambient UVR (Figure 5) was high (summer = 38.49%; winter = 29.42%) in relation to the average percentage of ambient UVR (summer = 30.79%; winter = 26.61%) for all the car guards during both seasons in part due to the absence of shade in the study area. This study's findings are consistent with those of Nkogatse *et al.* (2019) conducted during spring where high levels of solar UVR reached the earth's surface around noon. Moreover, the average exposure as a percentage of ambient UVR of all car guards was 24%, while the current study found the average percentage of ambient UVR of all car guards during both seasons (Figure 5) to be higher (summer = 30.79%; winter = 26.61%). The exposure values of car guards 2, 3, 4 and 5 during summer and car

guards 2, 3, 5 and 6 during winter had exceeded the average exposure as a percentage of ambient UVR due to their location of work i.e. the area of work assigned to them in the parking lot had no trees or shade structure close-by.

In terms of anatomical areas, the upper arm served as a basis for determining of solar UVR exposure at different anatomical areas such as the forehead, nose, cheek, nape, hands and shoulders. Different occupations require different bodily postures and repetition of tasks. Therefore, the level of exposure on an anatomical area is based on the task being performed (Milon *et al.*, 2014). Car guards usually perform their duties in an upright position, by directing cars out of the parking area by means of the movement of their arms and hands. This in turn, increases the chances of overexposure occurring on these anatomical areas. During both seasons (Figure 6a and 6b), the levels of solar UVR measured on the upper arm were lower than those estimated on other anatomical areas using equation 6 (vertex, forehead, nose, hands and shoulders). The vertex and shoulders were found to have the highest levels of solar UVR exposure amongst all car guards thus exceeding the TLV. Milon *et al.* (2014) found that horizontally exposed anatomical areas (shoulders) receive higher levels of solar UVR when compared to vertically exposed anatomical areas (face). The average percentage of exposure on the shoulders during summer was 20.70% and that of winter was 10.78%, whereas that of the face (forehead, nose and cheek) was 12.01% for summer and 6.25% for winter (Figure 7). The results obtained in this study are consistent with those obtained by Milon *et al.* (2014), indicating high exposure values occurring on the vertex, shoulders and hands. Even though exposure on certain anatomical areas (upper arm, cheek and nape) were lower, the finding that certain anatomical areas such as shoulders, hands, forehead and nose received higher exposure, means that the risk of developing acute effects such as sunburn remains. Cumulative lifetime exposure experienced by outdoor workers will increase the development of chronic effects such as skin cancer, since car guards in this study area had been in this industry for many years i.e. a car guard had reported to have been working at this particular location for 15 years (Nkogatse *et al.*, 2019).

High temperatures cause a range of health-related illnesses such as cramps and heat stroke and are classified as an occupational health hazard. Outdoor workers are at a particularly higher risk of experiencing these health-related illnesses since most of their day is spent outdoors with high temperatures, humidity and solar UVR exposure. Heat stress plays a role in the level of productivity of workers (Yi and Chan, 2017). Dunne *et al.* (2013) found a decrease in labour productivity especially during summer months because of the level of heat stress experienced by outdoor workers. According to the findings obtained by Yi and Chan (2017), high WBGT<sub>o</sub> levels were found to occur between 01:00 pm and 02:00 pm. WBGT<sub>o</sub>

values obtained in this study have indicated high values to occur between 12:00 pm and 03:00 pm. These findings are consistent with the solar UVR findings where high exposure values occur at the same time i.e. an increase in temperature (Table 2 and Figure 8) shows an increase in solar UVR exposure (Figure 4). Although findings in this study indicate low to moderate risk of adverse health effects occurring during both summer and winter, the risk to these health-related illnesses increase with cumulative exposure (Yi and Chan, 2017).

The UV index provides information based on the ability of the sun to cause sunburn and gives an indication for recommended protective measures required to prevent sunburn. Therefore, for each UV index range, there is a list of recommended protective measures providing protection against solar UVR exposure (SSAWC, 2016). The UV index obtained for summer ranged from three to six, and winter values ranges from two to three. Therefore, the level of risk associated with exposure for summer was between moderate to high, while risk in winter was between low to moderate. The findings, therefore, imply that the use of sunscreen, wearing of long-sleeved shirts and hats as well as seeking shade wherever available during midday has to be practiced by car guards irrespective of season (WHO, 2019b). The DB temperature, RH and UVI recorded during summer were higher than winter (Figure a and 8b). This is because the air during summer contains more moisture when compared to winter. The air during winter is dry, temperatures are lower and there is less moisture in the air required for saturation (North Carolina Climate Office, 2019).

Follow-up studies should focus on conducting long-term personal solar UVR exposure measurements on larger sample populations. In addition to solar UVR exposure measurements, studies evaluating the effectiveness of sun protective measures should also be carried out. These studies will provide a baseline to determine exposure values. Sun exposure awareness programs providing information and training should be developed to create awareness among outdoor workers regarding solar UVR exposure, its benefits and risks.

Limitations for this study include: (1) missing data for car guards 7 and 8 during winter because they were not willing to participate again, (2) no recording of data for a day during winter as the memory on the Genesis-UV dosimeters was full. Findings of this study were also limited by ambient air temperature and RH, and factors such as workload, acclimatization and clothing worn, were not considered. Therefore, sampling bias occurred because these factors do play a role in the heat stress experienced by outdoor workers.

### 3.6 Conclusion

Solar UVR exposure together with environmental conditions such as temperature has a profound effect on outdoor workers since they are often exposed to solar UVR during times when exposure levels are reported to be high. The Genesis-UV dosimeter was used for personal dosimetry and findings indicated that longer-term solar UVR exposure measurements provided relevant information on the amount of solar UVR received by workers in outdoor settings. Ambient measurements were conducted to identify the levels of solar UVR reaching the study area by means of hand-held UV monitors and environmental conditions were monitored using the QUESTemp<sup>®</sup>32/34. This study found that car guards were exposed to high levels of solar UVR throughout summer and winter. A strong positive correlation was found between WBGT and solar UVR during both seasons. The UV index varied between moderate to high during summer and low to medium during winter, indicating personal exposure increased with increasing UV index. Even though exposure on some days might not exceed the TLV, car guards are likely at risk of the adverse health effects associated with cumulative solar UVR exposure as some of them have indicated to have been in this industry for close to 15 years. Furthermore, variations in seasonal exposure to solar UVR do exist.

Outdoor working conditions make it impossible for workers to completely avoid solar UVR exposure through engineering measures and other methods of control due to the absence of shade structures and the movement of car guards from one place to another. The sampling area consisted of a large open area where each car guard had a specified area to work. Car guarding requires a lot of movement, i.e. the movement from one side to the other depending on the cars pulling out from the parking area. So even if trees were a means of providing shade, it would not cover the entire work area. However, personal protective measures together with education should be encouraged due to the lack of knowledge regarding solar UVR exposure in car guards. The level of personal protection required is based on the UV index and includes the following: wide-brimmed hats, long-sleeved clothing, sunglasses and the application of sunscreen with high sun protection factor (SPF) of 30 and higher.

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## CHAPTER 4: CONCLUDING CHAPTER

### 4.1 Final conclusions

Solar ultraviolet radiation (UVR) exposure plays a major role in the daily activities of outdoor workers. The risk for outdoor workers developing adverse health effects associated with solar UVR exposure is higher than that of indoor workers, irrespective of whether exposure is above or below the threshold limit value (TLV). This is because outdoor worker exposure is based on cumulative lifetime exposure (Makgabutlane and Wright, 2015). In many cases, working in the shade or changing working times is impossible. Therefore, personal protective measures are of importance in decreasing exposure levels to solar UVR, thereby minimizing the risk of developing adverse health effects.

The aim of this study is to quantify personal solar ultraviolet radiation (UVR) exposure of car guards during summer and winter. This was addressed by making use of the Genesis-UV dosimeters manufactured in Germany. Ambient measurements were also obtained to identify the levels of solar UVR reaching the earth's surface at the sampling area. These measurements were conducted using the hand-held UVI monitor manufactured by IDT Technology Limited, Hung Hom, Kowloon, Hong Kong. The results obtained during summer and winter were compared to determine whether differences in solar UVR exposure levels occurred between the two seasons. Levels of exposure on different anatomical areas were also determined to identify whether either horizontally exposed or vertically exposed anatomical areas received higher exposure levels. However, because upper arm was measured, an equation was used to identify the areas receiving higher levels of solar UVR.

Data obtained in this study have indicated average daily exposure levels of car guards to exceed the TLV during summer when compared to winter ( $p < 0.0001$ ; statistically significant).. Although results obtained have indicated exposure levels to be high during both seasons, the risk of developing adverse health effects associated with solar UVR exposure is higher during summer than in winter. The levels of exposure on different anatomical areas were higher than those received on the upper arm, and these values were statistically significant. Therefore, car guards need to be protected against the adverse health effects associated with solar UVR exposure. Because engineering measures and other methods of control are not feasible at the study site, personal protection and education are the main method of control that can be utilized by the car guards.

## 4.2 Hypotheses

The following was hypothesized in chapter 1:

1. Car guards will receive a significantly higher level of solar UVR during summer than in winter.

Findings of this study indicated personal solar UVR exposure of car guards to be higher during summer than in winter. The average of the total daily personal solar UVR exposure for car guards during summer was 11.50 SED, whilst that of winter was 5.47 SED. These differences are statistically significant ( $p < 0.0001$ ). Therefore, the risk of sunburn and associated solar UVR health effects are more likely to occur during summer than winter. This hypothesis is accepted.

2. Car guards will receive lower exposure on the upper arm (vertically positioned) than on other anatomical areas (horizontally positioned) such as the shoulders and hands.

The results obtained from this study show that the average of the total daily upper arm exposure (summer = 11.50%; winter = 5.99%) was lower than that of other anatomical areas such as the shoulders (summer = 20.70%; winter = 10.78%) and hands (summer = 16.87%; winter = 8.78%). It can be concluded that the findings of this study relate to those of Wright *et al.* (2004), ICNIRP (2010) and Milon *et al.* (2014) where the fact that horizontally exposed anatomical areas receive higher levels of solar UVR when compared to vertically exposed areas is acknowledged. Therefore, this hypothesis is accepted.

3. It was therefore hypothesized that an increase in WBGT will lead to an increase in solar UVR exposure of car guards.

The data obtained in this study has indicated that WBGT values during summer and winter has increased from 11:00 am to 02:00 pm, as is the same for solar UVR exposure of car guards. Thus, this study indicated that an increase in WBGT causes an increase in solar UVR exposure. Therefore, this hypothesis is accepted.

## 4.3 Limitations

- The New Zealand electronic dosimeters meant to measure ambient solar UVR only worked for three days during the winter measuring period. Therefore, they could not be relied upon and as a replacement, the measured ultraviolet index (UVI) values were used for comparison of ambient solar UVR between seasons.

- Studies conducted by ICNIRP (2010) and Wright *et al.* (2004) have indicated that exposure on horizontally exposed anatomical areas (head and shoulders) would be higher than exposure occurring on vertically exposed anatomical areas (upper arm and legs). The fact that the Genesis-UV dosimeters used to measure personal solar UVR exposure are designed for placement on the upper arm presents a limitation to the study.
- On one occasion during the winter measurement period, the data of majority of the participants except for one, could not be obtained. The error had occurred because of the limited storage capacity available on the dosimeters. To solve this issue, dosimeter data had to be uploaded regularly to clear previous data, thus making space available for new data to be recorded. An extra day of measurements could not be worked into the schedule due to the sharing of dosimeters amongst three different studies.

#### **4.4 Recommendations**

Protection against solar UVR exposure can be challenging for car guards because they are independent contractors and are therefore only registered with the security company as per requirements of the Private Security and Industry Regulation Act 56 of 2001 (PSIRA, 2014). In other words, these car guards pay a daily fee which allows them to be allocated to a specific area where they can watch over parked cars while owners do their shopping. The car guards do not receive any salaries from the security company. Their income is based purely on the money given to them in the form of tips by people whose cars they have watched.

Car guards who work the day shift (09:00 am – 03:00 pm) spend their entire work shift in the sun as there is no shade available at the shopping area where this research was undertaken. Taking a break is seen as a luxury car guards do not owe to themselves for fear of losing out on the tips from car owners. Additionally, a previous study has shown that car guards lack the required knowledge on the UV radiation from the sun as an occupational hazard as well as of the implementation of protective measures (Nkogatse *et al.*, 2019). It is therefore, recommended that the security company may as a sign of goodwill provide information and training to the car guards, thus making them aware of solar UVR, its exposure and effects associated with exposure, precautionary measures available and the importance of these precautionary measures. If possible, the mall could plant trees that could provide additional shade in the parking area of the shopping centre.

Additional protective measures are as follows and should be adhered to at all times irrespective of season or weather conditions (Morganroth *et al.*, 2013; Lucas *et al.*, 2016; US FDA, 2017):

- Clothing provides protection against solar UVR by scattering the UV rays. Therefore, clothing made from tightly woven, heavier fabrics such as polyester, wool, nylon and silk is preferred as they provide the highest form of protection. Dark coloured fabrics also play a role in providing protection to solar UVR. However, clothing made from these fabrics, are not always feasible to use as many of them contribute to the heat experienced by the body. In most cases, cotton is used as the preferred fabric of clothing, and the ultraviolet protection factor (UPF) provided by this fabric increases overtime as the fabric shrinks after washing. Long-sleeved shirts and long pants should be worn, thereby providing protection to the arms and legs against solar UVR exposure.
- Wide-brimmed hats that cover the ears and neck or even umbrella-type-hats providing sufficient protection of the facial area and shoulders should be worn.
- Tight-fitting sunglasses with UVA and UVB filters which provide protection for the eyes against direct and reflected solar UVR should form part of the protective equipment.
- Sun protection factor (SPF) indicates the level of protection provided by a sunscreen against the UVB ray therefore, the higher the SPF, the greater level of protection provided against UVB. SPF 15 blocks 93% of UVB, SPF 30 blocks 97% of UVB and SPF 50 blocks 98% of UVB. Therefore, it is recommended that sunscreens with a high sun protection factor (SPF) ranging from 30 or above should be used. This should be applied 30 minutes prior to exposure on all areas of the body that will be exposed to sunlight. This initial application of sunscreen should be followed up by reapplication every two hours. The amount of two milligrams per centimetre squared ( $\text{mg}/\text{cm}^2$ ) of skin (2 tablespoons) should be applied on an average sized adult. The use of sunscreen is said to reduce the risk of sunburn, photoaging and skin cancer.
- Car guards should undergo regular medical surveillance (at least once a year) at primary health care facilities. This will help to identify whether or not a car guard is affected by any of the adverse health effects associated with solar UVR exposure, together with determining their personal risk of exposure. If a car guard is affected, early intervention can be sought.

#### **4.5 Future studies**

- More studies based on determining personal solar UVR exposure of outdoor workers in different work settings and provinces around South Africa are required.

- Actual studies based on measuring solar UVR on different anatomical areas should be conducted rather than extrapolating data from the upper arm.
- A study based on car guard exposure during autumn at the same sampling area should be conducted to compare the results obtained for all four seasons.
- The effectiveness of training, education, and the use of personal protective measures should be evaluated in future studies, since training had been provided to car guards during the study. Therefore, studies evaluating whether the training provided has been adhered to and the effectiveness thereof should be evaluated.
- A dosimeter that can be placed on additional anatomical areas such as the wrist, vertex, neck and shoulder, or even the placement of dosimeters on both arms (left and right arm) to compare data will be ideal. Thus, the option of using poly-sulphone badges amongst others should be investigated.

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# ANNEXURES

## ANNEXURE A: HREC LETTER OF APPROVAL



Private Bag X1290, Potchefstroom  
South Africa 2520

Tel: 018 299-1111/2222  
Fax: 018 299-4910  
Web: <http://www.nwu.ac.za>

**Research Ethics Regulatory Committee**  
Tel: 018 299-4849  
Email: [nkosinathi.machine@nwu.ac.za](mailto:nkosinathi.machine@nwu.ac.za)

### ETHICS APPROVAL LETTER OF STUDY

Based on approval by the North West University Health Research Ethics Committee (NWU-HREC) on 27/11/2018, the NWU Health Research Ethics Committee hereby approves your study as indicated below. This implies that the North-West University Research Ethics Regulatory Committee (NWU-RERC) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

**Study title: Quantification of solar ultraviolet radiation exposure of car guards during summer and winter.**

**Study Leader/Supervisor (Principal Investigator)/Researcher: Ms MC Ramotsehoa**

**Student: AS Hadjee**

**Ethics number:**

|             |   |   |              |   |   |   |   |   |      |   |        |   |   |   |
|-------------|---|---|--------------|---|---|---|---|---|------|---|--------|---|---|---|
| N           | W | U | -            | 0 | 0 | 1 | 3 | 3 | -    | 1 | 8      | - | A | 1 |
| Institution |   |   | Study Number |   |   |   |   |   | Year |   | Status |   |   |   |

Status: S = Submission; R = Re-Submission; P = Provisional  
Authorisation; A = Authorisation

**Application Type: Single study**

**Commencement date: 2018/11/27**

**Risk:**

**Minimal**

**Expiry date: 2019/11/30**

**Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of an annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.**

#### Special in process conditions of the research for approval (if applicable):

- Please provide the HREC with copies of the goodwill permission letters from the parking manager (mediator) and car guard supervisors, indicating that the study can proceed.

#### General conditions:

*While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:*

- *The study leader/supervisor (principle investigator)/researcher must report in the prescribed format to the NWU-HREC:*
  - *annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and*
  - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*

- *The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the NWU-HREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*
- *Annually a number of studies may be randomly selected for an external audit.*
- *The date of approval indicates the first date that the study may be started.*
- *In the interest of ethical responsibility the NWU-RERC and NWU-HREC reserves the right to:*
  - *request access to any information or data at any time during the course or after completion of the study;*
  - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the study are revealed or suspected;*
    - *it becomes apparent that any relevant information was withheld from the NWU-HREC or that information has been false or misrepresented;*
    - *submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or*
    - *new institutional rules, national legislation or international conventions deem it necessary.*
- *NWU-HREC can be contacted for further information or any report templates via [Ethics-HRECApply@nwu.ac.za](mailto:Ethics-HRECApply@nwu.ac.za) or 018 299 1206.*

The NWU-HREC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the NWU-HREC or the NWU-RERC for any further enquiries or requests for assistance.

Yours sincerely



Digitally signed by Wayne  
Towers  
Date: 2018.12.04  
12:30:42 +02'00'

Prof Wayne Towers  
Chair NWU Health Research Ethics Committee

Current details: (22351930) M:\DSS1\8533\Monitoring and Reporting Cluster\Ethics\Certificates\Templates\Research Ethics Approval Letters\9.1.5.4.2 HREC Ethical Approval Letter.docm  
3 December 2018

File reference: 9.1.5.4.2

## ANNEXURE B: INFORMED CONSENT



Private Bag X1290, Potchefstroom  
South Africa 2520  
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Web: <http://www.nwu.ac.za>



### **INFORMED CONSENT DOCUMENTATION FOR CAR GUARDS WHO ARE INDEPENDENT CONTRACTORS UNDER CB SECURITY AT POTCHEFSTROOM, NORTH WEST PROVINCE.**

**TITLE OF THE RESEARCH STUDY:** Quantification of solar ultraviolet radiation exposure of car guards during summer and winter.

**ETHICS REFERENCE NUMBERS:** NWU-00133-18-S1

**PRINCIPAL INVESTIGATOR:** Ramotsehoa MC

**POST GRADUATE STUDENT:** Hadjee AS

**ADDRESS:** OHHRI

**CONTACT NUMBER:** 018 299 2062 / 076 826 1660

You are being invited to take part in a **research study** that forms part of a research focus within the Occupational Hygiene and Health Research Initiative (OHHRI) niche area of the North-West University, Potchefstroom. Please take some time to read the information presented here, which will explain the details of this study. Please ask the researcher or person explaining the research to you any questions about any part of this study that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research is about and how you might be involved. Also, your participation is **entirely voluntary** and you are free to say no to participate. If you

say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part now.

This study has been approved by the **Health Research Ethics Committee of the Faculty of Health Sciences of the North-West University (NWU-00133-18-S1)** and will be conducted according to the ethical guidelines and principles of Ethics in Health Research: Principles, Processes and Structures (DoH, 2015) and other international ethical guidelines applicable to this study. It might be necessary for the research ethics committee members or other relevant people to inspect the research records.

#### **What is this research study all about?**

- *We plan to measure the amount of solar ultraviolet radiation (UVR) that you receive when you work day-shift (9:00 am – 3:00 pm) using UVR electronic dosimeters.*
- *This study will be conducted in Potchefstroom at the place you report for work (Mooirivier mall) for a period of ten days during summer and or winter. The study will involve personal measurements with experienced researchers trained in conducting occupational hygiene surveys. A minimum of 10 and maximum of 12 participants will be included in this study.*

#### **Why have you been invited to participate?**

- *You are invited to be part of this research because you work outside (outdoors) as a car guard at Mooirivier mall, Potchefstroom and the amount of solar ultraviolet radiation (from the sun), that car guards receive during day shift over longer periods has been measured only during spring in South Africa. Your results will form a baseline for exposure of car guards. You will also gain knowledge about the health effects of solar UVR, which will be of benefit to you and your family.*
- *You also fit the research because you work day shift (9:00 am – 3:00 pm) for six or more hours and for at least five or more days during which the study will run.*
- *You will not be able to take part in this research if your dayshift is less than four hours a day, you work only nightshifts (3:00 pm – 7:00 pm) in the month of measurements and if you are under the age of 18 years.*

#### **What will be expected of you?**

- *You will be expected to wear three dosimeters which measure the amount of ultra violet radiation you receive from the sun. You will place the dosimeters on the outside of your upper arm and wrist (arm dependent on your choice) each day you report for work, for your full dayshift. We will give you the dosimeters before the start of your dayshift and collect them at the end of the shift. We will give you a demonstration on how and where to wear the dosimeters. This will happen for a period of ten days. The attachment and removal of dosimeters will take place in the mall management office.*

#### **Will you gain anything from taking part in this research?**

- *The gains for you if you take part in this study, you will know more about solar UVR and its effects as well as the methods that are available for use in everyday life to reduce exposure to solar UVR.*

- The other gains of the study are for the researcher who will gain more knowledge regarding the exposure of outdoor workers to solar UVR. This study will also provide a baseline of exposure of outdoor workers particularly car guards to solar UVR, which will motivate further research in these occupational groups elsewhere. The results of this study may in the long run motivate the development of sun care programmes in outdoor work settings where such programmes do not exist (this is a benefit for outdoor workers in general including you).

**Are there risks involved in you taking part in this research and what will be done to prevent them?**

- The risks to you in this study is minimal, and this includes a slight form of discomfort and irritation that might occur on the wrist and upper arm from the dosimeter straps if they are placed too tight but will be limited by allowing you to adjust the straps according to your level of comfort in such a manner that the dosimeter does not move from the required area of measurement.
- There are more gains for you in joining this study than there are risks.

**How will we protect your confidentiality and who will see your findings?**

- Apart from this consent form, your name will not be required or appear in any other document. In the place of your name, we will use a code throughout the study. The name of the company you are contracted to or your workplace location will not appear anywhere in the study documentation. The wearing of dosimeters will take place in the mall management offices and all the dosimeters will be stored in a locked office at North West University, afterhours and on weekends. Your results will be kept confidential by storing them in the database using the codes assigned to you and ensuring that they are not linked to you. Only the researchers will be able to look at your findings. We will save all the findings from this study in a personal computer. Findings will be kept safe by locking hard copies in locked cupboards in the researcher's office and for electronic data it will password protected. We will remove/delete the readings from the dosimeters once we have transferred them into a computer with password protection. The findings will later be reported in a research article which will be published in an accredited journal, once again the name of the company you are contracted to or your place of work will not appear anywhere in the research article. Data will be stored for 10 years, after which it will be destroyed by means of a shredding machine.

**What will happen with the findings or samples?**

- We will share the findings of the study with the GENESIS team in Germany. We will not reveal your name, your place of work, or the province where your workplace is located. This, we will do to protect your privacy/identity. The team from Germany will only know that the data comes from South Africa. The data obtained from this study may be used for future projects.

**How will you know about the results of this research?**

- All the car guards as well as the security company will receive a report on this research on the 30<sup>th</sup> of December 2019 in the form of a presentation. The report will contain findings of the personal measurements, what they mean as well as the best way of protecting yourselves against the harmful effects of the sun. During this

*presentation, you will have an opportunity to ask any questions. You will also be given pamphlets which you can keep. The pamphlets will have information on the findings and methods you can use to protect yourself against the harmful effects of the sun.*

- *You will be informed of any new relevant findings whenever it becomes available as we continue with studies in the future by informing the security company, parking managers and you as a car guard.*

#### **Will you be paid to take part in this study and are there any costs for you?**

*This study is funded by the Faculty of Health Science.*

*No, you will not be paid to take part in the study because we will conduct the study during your normal working day as you report for work and your work schedules will continue in a normal way.*

*There will be no traveling expenses for you, since the site where the study will take place is where you work.*

*There are no costs involved for you, if you do take part in this study.*

*You will receive a grocery-shopping voucher at the end of the study as token of appreciation.*

#### **Is there anything else that you should know or do?**

- *You can contact Ameera Hadjee at 082 056 5777 or Cynthia Ramotsehoa at 018 299 2062/ 076 826 1660 if you have any further questions or have any problems.*
- *You can also contact the Health Research Ethics Committee via Mrs Carolien van Zyl at 018 299 1206 or [carolien.vanzyl@nwu.ac.za](mailto:carolien.vanzyl@nwu.ac.za) if you have any concerns that were not answered about the research or if you have complaints about the research.*
- *You will receive a copy of this information and consent form for your own purposes.*

### Declaration by participant

By signing below, I ..... agree to take part in the research study titled: Quantification of solar ultraviolet radiation exposure of car guards during summer and winter. I also consent to the data being shared with the Genesis team in Germany.

I declare that:

- I have read this information/it was explained to me by a trusted person in a language with which I am fluent and comfortable.
- The research was clearly explained to me.
- I have had a chance to ask questions to both the person getting the consent from me, as well as the researcher and all my questions have been answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be handled in a negative way if I do so.
- I may be asked to leave the study before it has finished, if the researcher feels it is in the best interest, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... on (*date*) ..... 20....

.....  
**Signature of participant**

.....  
**Signature of witness**

### Declaration by person obtaining consent

I (*name*) ..... declare that:

- I clearly and in detail explained the information in this document to  
.....
- I did/did not use an interpreter.

- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I gave him/her time to discuss it with others if he/she wished to do so.

Signed at (*place*) ..... on (*date*) ..... 20....

.....  
**Signature of person obtaining consent**

#### **Declaration by researcher**

I (*name*) ..... declare that:

- I explained the information in this document to .....  
or I had it explained by ..... who I trained for this purpose.
- I did/did not use an interpreter
- I encouraged him/her to ask questions and took adequate time to answer them  
or I was available should he/she want to ask any further questions.
- The informed consent was obtained by an independent person.
- I am satisfied that he/she adequately understands all aspects of the research, as described above.
- I am satisfied that he/she had time to discuss it with others if he/she wished to do so.

Signed at (*place*) ..... on (*date*) ..... 20....

.....  
**Signature of researcher**

## ANNEXURE C: LANGUAGE EDITING CERTIFICATE

*Woorde wat werk / Working Words*

Venita de Kock  
BA Honns. HOD(G)  
Member Professional Editors' Guild

 4698, LEEUPOORT 0468

 0845885008

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### LANGUAGE EDITING STATEMENT

2019 - 11 - 19

I, Jannetje Levina De Kock hereby declare that the mini-dissertation

*Exposure of car guards to solar ultraviolet radiation  
during summer and winter*  
by

Ameera Hadjee

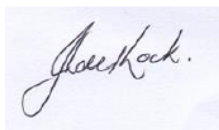
for submission to the

the NWU

in the Niche area Occupational Hygiene and Health Research Initiative (OHHRI)

- has been edited for language correctness and spelling.
- has been edited for consistency (repetition, long sentences, logical flow)

No changes have been made to the document's substance and structure (nature of academic content and argument in the discipline, chapter and section structure and headings, order and balance of content, referencing style and quality).



J L DE KOCK

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