ENVIRONMENTAL OR OCCUPATIONAL EXPOSURE TO OPTICAL RADIATION: RISK EVALUATION, HEALTH EFFECTS AND PREVENTION - TANGIBLE INNOVATION FOR PUBLIC AND OCCUPATIONAL HEALTH?

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ENVIRONMENTAL OR OCCUPATIONAL EXPOSURE TO OPTICAL RADIATION: RISK EVALUATION, HEALTH EFFECTS AND PREVENTION - TANGIBLE INNOVATION FOR PUBLIC AND OCCUPATIONAL HEALTH?

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Editorial: Environmental or occupational exposure to optical radiation: Risk evaluation, health effects and prevention - tangible innovation for public and occupational health?

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KEYWORDS

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Editorial on the Research Topic
Environmental or occupational exposure to optical radiation: Risk evaluation, health effects and prevention - tangible innovation for public and occupational health?

This Special Issue addresses the Research Topic of exposure to optical radiation (OR), considering in particular solar radiation and the health consequences of an excessive exposure, the issues related to risk evaluation and the indications for an appropriate prevention of this environmental and occupational hazard. The Sun emits all the types of OR, including infrared, visible and ultraviolet radiation (UVR) (1). This latter is the most harmful component of OR, able to induce not only short-term adverse effects mainly at the eyes and the skin, but also long term ones, including cancers (2). With regard to outdoor workers (OW) exposed to solar UVR, scientific literature proves a high burden of cancers related to this exposure, especially keratinocytes carcinomas, as recently reported in a systematic review (3), even if these pathologies are often under-recognized, when not totally neglected, as "occupational diseases" (2, 3). From an occupational hazard perspective, UVR is currently acknowledged as the occupational carcinogenic agent the most subjects are exposed to, and it is also a known risk factors for various other eye and skin acute and chronic diseases: the acute ones include sunburns, photoconjunctivitis and photokeratitis, while among the chronic ones there are the above-mentioned skin cancers, as well as pterygium and cataract for the eyes. These diseases are included in the overview on health risks associated with excessive exposure to solar UVR among OW by Wright and Norval, published under this Special Issue and with a specific focus on a Country as South Africa, for which up to now only a few reports on work-related OR risk were available. Moreover, in most Countries of the world there are no recognized criteria for the recognition and prevention of UVR-related occupational skin cancers, as well as no valid exposure limit values for solar UVR exposure, as highlighted by Wittlich, who proposes here a series of brand new criteria of occupational health prevention for solar UVR exposed OW. Wittlich also underlines that it is extremely important to conduct extensive and rigorous measurements campaigns to identify solar UVR exposure levels posing OW at risk for adverse effects. This was done by Heepenstrick et al., who showed different reliable approaches for an effective dosimetry to be applied in various outdoor activities. With regard to the exposure of the eyes, Marro et al. reviewed the available methods reported in literature, along with their limitations, to study ocular UVR exposure and its implications for health.

Shifting to prevention of adverse effects, one of the main topics currently addressed in scientific research is the studying of the most effective interventions to be applied for the protection of OW and of the general public, with the final aim of reducing the burden of skin cancers. This is the topic of a systematic review being currently conducted by an international research group, with its protocol registered in PROSPERO and fully published under the present Special Issue (Modenese et al.). In addition, a specific intervention for Dutch construction workers has been designed by Keurentjes et al.(a), who first published the protocol for their non-randomized intervention study, and then reported here the first results collected with a pilot study aimed at stimulating the use of sunscreen among construction workers. This study reveals that, even if provided, construction workers scarcely use sunscreen, although they report of being sufficiently informed on solar UVR risk and those using sunscreens seem satisfied with them by Keurentjes et al.(b),. The results of another European intervention in this field are reported in the Danish study by Jacobsen et al., indicating that the awareness of occupational skin cancer risk and the perception of the importance of prevention and sun protection at work amongst outdoor workers can be improved with a specific multicomponent intervention.

Finally, the present Special Issue also reminds us that we are in the climate changing era, and Sun-related occupational and environmental hazards are not limited to solar UVR: as a matter of fact, heat waves and their possible adverse health consequences are becoming a serious concern for the performance of occupational and leisure outdoor activities worldwide: in this context, the study conducted by Wang et al. highlights an insufficient awareness of military personnel in China with respect to preventive and first-aid measures against heat-related illnesses, indicating, as it happens also for UVR-related effects, an urgent need of targeted educational interventions.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Protection Against Solar Ultraviolet Radiation in Outdoor Construction Workers: Study Protocol for a Non-randomized Controlled Intervention Study

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Introduction: Non-melanoma skin cancer (NMSC) incidence is increasing, and occupational solar exposure contributes greatly to the overall lifetime ultraviolet radiation (UVR) dose. This is reflected in an excess risk of NMSC showing up to three-fold increase in outdoor workers. Risk of NMSC can be reduced if appropriate measures to reduce UVR-exposure are taken. Regular use of sunscreens showed reduced risk of NMSC. However, sun-safety behavior in outdoor workers is poor. The objective of this study is to investigate the effectiveness of an intervention aiming at increasing sunscreen use by construction workers.

Methods: This non-randomized controlled intervention study is comprised of two intervention and two control groups recruited at four different construction sites in the Netherlands. The study population comprises ∼200 construction workers, aged 18 years or older, followed during 12 weeks. The intervention consists of providing dispensers with sunscreens (SPF 50+) at construction sites and regular feedback on the application achieved by continuous electronic monitoring. All groups will receive basic information on UV-exposure and skin protection. Stratum corneum (SC) samples will be collected for measurement of biomarkers to assess internal UV-dose. External UV-dose will be assessed by personal UV-sensors worn by the workers during work-shifts in both groups. To detect presence of actinic keratosis (AK) or NMSC, a skin check of body parts exposed to the sun will be performed at the end of the study. The effect of the intervention will be assessed from data on self-reported sunscreen use by means of questionnaires collected on baseline and after 12 weeks of intervention (primary outcome). Levels of SC biomarkers of internal UV-dose, external UV-dose, number of sunburn episodes, and prevalence of NMSC including AK will be assessed as secondary outcomes. The electronically monitored sunscreen consumption will be assessed as process outcome.

Discussion: This study is intended to provide evidence of the effectiveness of a technology-driven intervention to increase sunscreen use in outdoor construction workers. Furthermore, it will increase insight in the UV-protective behavior, external and internal UV-exposure, and the prevalence of NMSC, including AK, in construction workers.

Trial Registration: The Netherlands Trial Register (NTR): NL8462 Registered on March 19, 2020.

Keywords: outdoor workers, solar radiation, intervention, non-melanoma skin cancer, use of sunscreen, occupational disease, stratum corneum, biomarkers

INTRODUCTION

Globally, non-melanoma skin cancers (NMSC) are the most common cancers in fair-skinned populations (1). Solar ultraviolet radiation (UVR) is the main cause of NMSC in fair-skinned people, responsible for ∼50–70% of squamous cell carcinoma (SCC) and 50–90% of basal cell carcinoma (BCC) (2, 3). Recently, systematic reviews found that the risk among outdoor workers was raised for SCC and actinic keratosis (AK) by 77%, and for BCC by 43% respectively, compared with the general population (4, 5). Occupational solar exposure contributes greatly to the overall lifetime UV dose. This is reflected in an excess risk of NMSC showing up to three-fold increase in outdoor workers (6). High and increasing incidence rates and frequent recurrence have considerable impact on life and productivity of affected workers. This burden is recognized by the World Health Organization (WHO) and the International Labour Organization (ILO) in a recently published a protocol for a systematic review on the effect of occupational UVR-exposure on NMSC prevalence (7). In six EU countries NMSC has been recognized as an occupational disease (8). NMSC can largely be avoided if appropriate measures to reduce UVR are taken. Several prevention strategies have been developed based on educational programs or use of sunscreens and protective clothing such as long-sleeved shirts and wide-brimmed hats (9). Sunscreen is shown to be an efficient strategy to reduce UVR exposure and its consequences (10, 11). It is a feasible measure to adopt by outdoor workers (12–14), and when used regularly, sunscreens are able to prevent the formation of actinic keratosis and eventually squamous cell carcinoma (10, 11). However, previous research revealed several barriers to using sunscreen, such as the common belief that people with a tanned or dark skin are not at risk for skin cancer and protective measures are not necessary (10, 15), or that sunscreens are expensive (16). Also, generally positive attitudes toward a tanned skin are associated with a decrease in sunscreen use, preventing outdoor workers from taking sun protection seriously (10, 17). Putting on sunscreen is seen as a disturbance and a nuisance, for example it is messy and time-consuming to apply (10, 16, 17). Furthermore, many outdoor workers are male and they may feel it is not masculine to protect themselves from the sun (10, 18), especially around other men (10, 19). Sun-safety behavior among outdoor workers is still poor (10, 20, 21), with examples of 75% of operating engineers seldom or never using sunscreen and 80% of those workers reporting sunburns during the summer (10). However, in another study the majority of outdoor workers did use sunscreen during the summer but they used it incorrectly regarding time, frequency and amount applied (21). Additionally, a recently published meta-analysis showed that the most effective intervention for promoting sunscreen use is providing free sunscreen (22).

Several gaps in the current knowledge are to be filled, these are the prevalence of NMSC including AK, the occupational UV-exposure, and ultimately the effectiveness of an intervention aimed at increasing of sunscreen use in outdoor workers. Well-designed and sufficiently powered studies with adequate adjustment for confounding factors are required to provide more accurate risk estimates for occupational NMSC (23). Data on UV-exposure (external and internal, i.e., the UV-dose that reaches the surface of the skin and the UV-dose absorbed by the skin, respectively), presence of NMSC (including AK), and sunscreen use in outdoor workers in the Netherlands are not yet available.

Objectives

The objectives of this study are (i) to evaluate an intervention consisting of the facilitation of sunscreen dispensers with continuous electronic monitoring and feedback on the use of sunscreens at worksites, and (ii) to assess occupational UV-exposure and the prevalence of NMSC, including AK, among construction workers.

Hypothesis

We hypothesize that provision of sunscreen dispensers (facilitation), accompanied by continuous monitoring and intermittent feedback on sunscreen use (awareness and feedback), will significantly increase the use of sunscreen amongst construction workers compared to a control group.

METHODS/DESIGN

Design and Setting

This is a non-randomized controlled intervention study in construction workers. The duration is 12 weeks, from May to July. The measurements will consist of questionnaires, clinical and biochemical assessments, personal UV-dosimetry, and continuous electronic sunscreen consumption records. When reporting the results of this study we will adhere to

Abbreviations: AK, actinic keratosis; ANOVA, analysis of variance; BCC, basal cell carcinoma; HPLC, high performance liquid chromatography; MSD, mesoscale discovery; NMSC, non-melanoma skin cancer; SC, stratum corneum; SCC, squamous cell carcinoma; SOP, standard operating procedure; SPF, sun protection factor; UCA, urocanic acid; tUCA, trans-urocanic acid; cUCA, cis-urocanic acid; UV, ultraviolet; UVR, ultraviolet radiation.

the Transparent Reporting of Evaluations with Non-randomized Designs (TREND) statement (24).

A nationwide construction company in the Netherlands will appoint four comparable construction sites suitable for the study. Two sites will serve as the intervention groups and the other two construction sites will serve as the control groups. To minimize potential bias induced by non-randomization, the control groups will be matched to the intervention groups regarding worksites and job tasks, geographical location of the worksites, and time-frame. To avoid contamination bias, the whole construction site will be assigned en masse to the intervention group and there will be no rotation of workers between the four workplaces.

A process evaluation of the intervention will take place in the closing questionnaire to support a future implementation process.

Participants and Recruitment

The participants in this study are construction workers, engaged in outdoor work activities. The participants are aged 18 years or older, have expressed the willingness to comply with the study protocol, and provided informed consent (inclusion criteria). The construction workers will be recruited by the occupational health service of their company. The construction workers will receive a letter from the investigators stating the purpose of the study, a short version of the study protocol, and a brief description of the expected burden for the participant during the intervention. Information regarding the intervention will be omitted for the participants in the control groups. The participants will be advised to contact the independent physician if they have additional questions regarding health risk associated with the study. The participants will be asked for their consent by the investigator and sign an informed consent form. The participants will have at least 24 h to consider their decision.

Products Used in the Intervention Groups

The electronic dispensers placed on the construction sites in the intervention groups will be filled with sunscreen Stokoderm® Sun Protect 50 PURE SPF 50 UV skin protection lotion for professional use. This product is a cosmetic product regulated by and complying with Regulation EC no. 1223/2009 (as amended) on Cosmetics Products. The main ingredients are ethylhexyl salicylate, bis-ethylhexyloxyphenol methoxyphenyl triazine, butyl methoxydibenzoylmethane, octocrylene, and homosalate.

Description of the Study Procedures and Intervention

The flowchart of the study design is shown in **Figure 1**. During the recruitment phase, the researchers will visit the construction sites. The construction workers will be informed on the study protocol in both oral and written form by the investigator. Written informed consent will be obtained. The suitability of the construction worker to participate in the study will be checked using the inclusion criteria, as mentioned before (in section Participants and Recruitment). Construction workers fulfilling the criteria will be enrolled in the study.

The researchers will visit the worksites of the intervention and control groups three times (at T = 0, T = 6 weeks, and T = 12 weeks). The participants will be asked to fill in a questionnaire at the start (T = 0) and the end of the study (T = 12 weeks). At T = 0, T = 6 weeks, and T = 12 weeks, stratum corneum (SC) samples will be collected, and measurements of personal UV-exposure by using personal dosimeters will be performed during work shifts for 1 week (Monday to Friday). At the end of the study (T = 12 weeks), the participants will undergo a skin check of the sun-exposed body parts for the presence of AK and NMSC by a trained investigator (physician). The intervention and control groups will receive basic information (i.e., a 15-min Powerpoint presentation) on the nature of the study and sun-safety and UV-protective behavior at the beginning of the study (baseline).

Questionnaires

The questionnaire will include questions about age, gender, country of origin, work status as outdoor worker and job characteristics (e.g., job task), number of years in current profession and previous jobs, sun-related risk knowledge, attitudes, barriers for using sunscreen, outside leisure-time spending, and UV-protective behaviors (e.g., use of sunscreen). In the closing questionnaire (T = 12 weeks) an additional question about the number of sunburn episodes during the study period will be included. In the intervention groups questions about satisfaction with the provided sunscreen and their opinion about the effectiveness of the feedback posters will be added (see Intervention Groups: Sunscreen Dispensers and Feedback Posters).

UV-Dosimetry

A limited number of participants in all groups ($n = 10$ per each group) will wear a UV-dosimeter during their work shift during 1 week at each time point (T = 0, T = 6 weeks, T = 12 weeks). The selection of outdoor workers who will wear the dosimeters will be performed in way that ensures a maximal variability of job tasks. The Scienterra UV-dosimeter, which will be used in the present study, has proved to be a reliable method to measure external UVB-exposure in outdoor workers (25), and has been used previously to study the influence of human behavior on personal UV-exposure (26). The personal UV-dosimeter will be worn on the left upper arm, which has shown to be a reliable, practical and convenient body site in a previous study (27), and it will not interfere with work tasks.

Collection of SC Samples: Procedure of Tape Stripping

During the study, SC samples will be collected at the beginning (T = 0), half-way (T = 6 weeks), and at the end of the study (T = 12 weeks) in both groups. The SC will be collected by using adhesive tape strips with a minimally invasive, non-painful method which is extensively used in experimental studies (28–30). Adhesive tape discs (3.8 cm^2, D-Squame; CuDerm, Dallas, TX, USA) will be attached to the skin. Each tape is pressed on the skin for 5 sec with standardized force, using a disc pressure applicator (CuDerm). The tape strips will be removed gently with tweezers and stored in a closed vial at −80°C until analysis. The samples will be taken from skin sites exposed to the sun (i.e., forehead), and a less-exposed skin site (i.e., behind the ear).

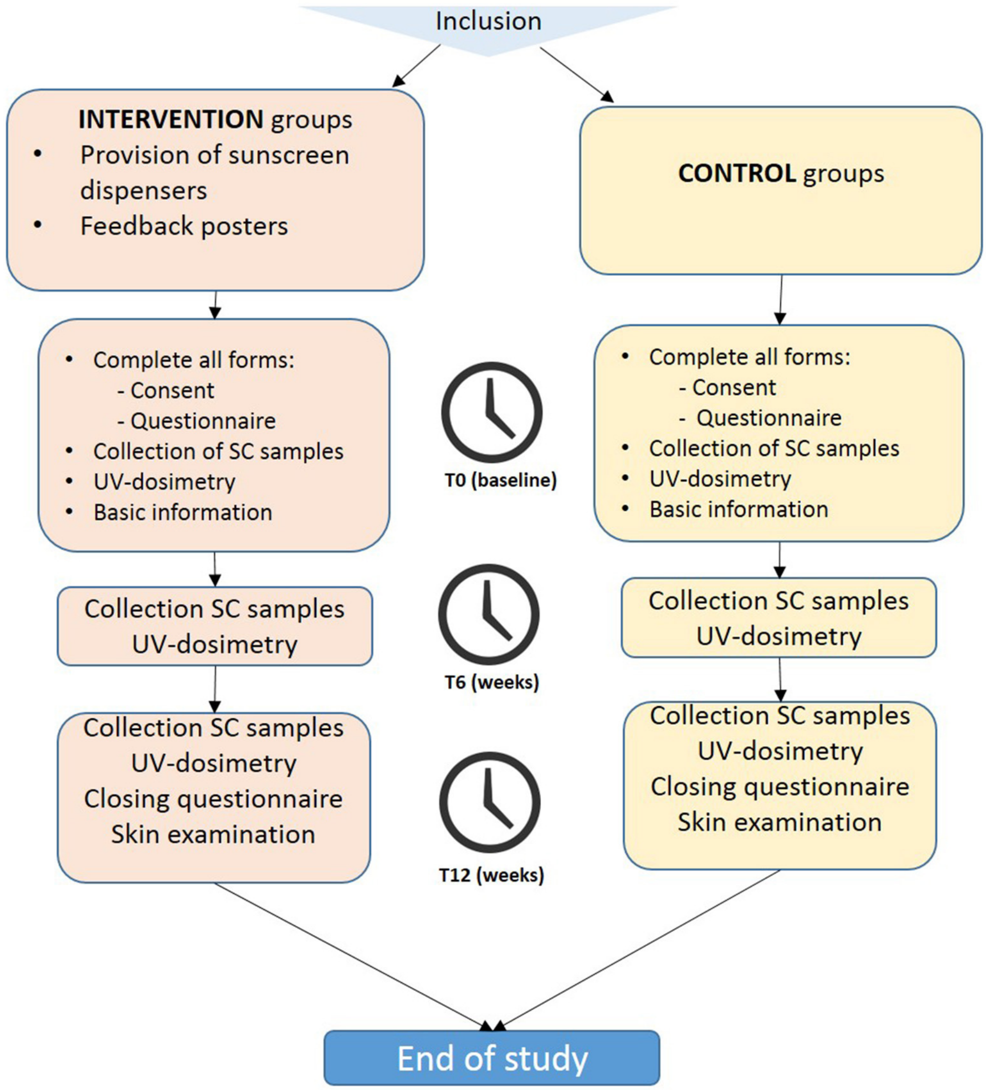

FIGURE 1 | Flowchart of the study design.

Analysis of the Markers of the Internal UV-Dose

The markers of the internal UV-dose will include the *cis*- and *trans*-isomers of urocanic acid (UCA), and immune markers of different signature such as matrix metalloproteinases (MMP), cytokines, and angiogenesis factors. The isomers of UCA are one of the most studied UVR-related biomarkers (31–34). *Trans*-urocanic acid (tUCA) is a major UVR-absorbing component in the epidermis and it isomerizes to the *cis*-form (cUCA) upon exposure to UVB in a dose-dependent manner until reaching a photo stationary state at ∼60–70% of total UCA (35). That makes cUCA a very specific marker as it is not endogenously present but is formed upon exposure to UVR (36). Immunological markers have been proposed to assess the effects of UVR-exposure (37–40), as the adverse effects of UVR might have occurred before visible changes occur (erythema of the skin), and furthermore, immune response in the skin plays an important role in UVR-mediated damage (41). Immunological markers might be in particular useful to assess repeated exposure to UVR (29).

The markers will be extracted from the tape using a buffer, and subsequently analyzed using an appropriate technique. For urocanic acid, HPLC (High Performance Liquid Chromatography) method will be used, and for cytokines the multiplex immuno-assay (MSD–Meso Scale Discovery LLC, Maryland, U.S.A.). For all analyses, standard operating procedures (SOP) will be used. The analysis of the markers will be performed blinded, the samples will be coded untraceable to the participants (the codes will be open after data analysis has been performed).

Skin Check

At the end of the study (T = 12 weeks), a skin check of the sun-exposed skin by a trained investigator (physician) will be performed on the participants of all groups. Besides examination for NMSC and AK, following clinical features (42), skin photo type following Fitzpatrick (43) will be recorded. Furthermore, skin photo damage will be assessed by the validated Glogau photo damage classification scale (44).

Intervention Groups: Sunscreen Dispensers and Feedback Posters

The intervention groups will be provided with electronic sunscreen dispensers (with monitoring system) installed at the construction site at readily accessible strategic places (canteen/offices etc.). The electronic dispenser, equipped with a Wi-Fi transmitter, continuously records each application event, providing information on the timing and frequency of sunscreen use during the work shift. The system provides robust and easy to interpret web-based reports on sunscreen use per dispenser. Data on use pattern (frequency, total consumption, moments of use) and trends will enable structured feedback on sunscreen use to be given to the construction workers to motivate and improve compliance. Feedback on sunscreen use will be provided using posters placed in proximity of the dispensers, and will be replaced with actual data every 2 weeks. To increase the readability and understanding of the information on the posters, visual aids will be used when possible. Recent systematic reviews found that processing a message in a colorful and illustrative format transmits the message more effectively (45, 46). Also, with the increase of foreign nationals in construction, the use of visual means for conveying health and safety messages is widely popular (45).

Outcome Measures

Primary Outcome

The individual frequency of sunscreen use will be derived from the questionnaires. When asked how often sunscreen is applied on a daily basis in the last month, the answer options are "never, seldom, sometimes, often, always." Difference in the frequency of sunscreen use between the intervention and control groups will serve as the primary outcome.

Secondary Outcomes

Several secondary outcomes will be assessed:

(i) Internal UV-dose will be determined by measuring the SC levels of UCA isomers and immunological markers measured in the intervention and control groups at T = 0, T = 6 weeks, and T = 12 weeks.
(ii) Levels of external UV-exposure in construction workers, measured using Scienterra UV-dosimeters at T = 0, T = 6 weeks, T = 12 weeks.
(iii) The prevalence of NMSC including AK in construction workers as assessed at T = 12 weeks by a skin check.
(iv) The number of reported episodes of sunburn during the study period as obtained from the closing questionnaire at T = 12 weeks.

Process Outcomes

(i) Pattern of sunscreen use derived from data generated by the electronic monitoring system of the sunscreen dispensers, in the intervention groups only. This will include frequency (averaged for the number of workers), time of use, association with UV-exposure and job task, averaged per person and day.
(ii) Pattern of sunscreen use in relation to the time after placing a poster with feedback concerning UV-index and sunscreen consumption (in the intervention groups only, derived from electronic monitoring).
(iii) Satisfaction with the intervention by the construction workers and employers as assessed by the closing questionnaire. The questions concern satisfaction with the sunscreen (ease of use, ability to perform job task etc.), and satisfaction with the placement of the dispensers (in the intervention groups only).
(iv) Changes in UV-protective behavior regarding sunscreen use. This will be assessed from the questionnaires collected at T = 0 and T = 12 weeks from the questions related to attitude and motivation to use sunscreen.
(v) Identification of possible barriers to using sunscreens will be assessed from the questionnaires collected at T = 0 and T = 12 weeks. The questions address barriers such as difficulty to implement in the work shift, disturbance of work tasks or negative comments from colleagues when applying sunscreen.
(vi) Knowledge about UV-exposure and UV-protection that will be assessed from the questionnaires at T = 0 and T = 12 weeks. Questions include awareness that applying of sunscreen is important even on cloudy days or on already tanned skin.

Power Calculation

The study is planned to include 200 participants. The sample size is based on the expectation regarding the change in sunscreen usage. There is no available data on sunscreen use in outdoor workers in the Netherlands, or the barriers for sunscreen use. Therefore, we based our calculations of the sample size on a Canadian study reporting that 25% of the outdoor workers used sunscreen regularly (47). We assumed that 25% of the outdoor workers in the control groups will use sunscreen, and that in the intervention groups we expect this percentage will increase up to 50%. To calculate the sample size, nQuery Advisor software (Statistical Solutions Ltd, Boston, MA, U.S.A.) was used (proportion, two groups, two-sided test). A sample size of 58 workers per group will have 80% power to detect a difference in proportion that equals at least 0.05 significance level. Taking into account possible drop-outs, 100 outdoor workers per group will be recruited.

Statistical Methods and Data Analysis

There will be no replacement of any individual subjects who withdraw. However, the characteristics (e.g., job task, age) and number of withdrawals will be monitored.

The characteristics of the construction workers (e.g., age) and job tasks will be presented by using descriptive statistics.

We will use the mean and standard deviation to describe normally distributed continuous variables and the median and interquartile range to describe non-normally distributed continuous variables. For the self-reported sunscreen usage data (primary outcome), counts and percentages to present categorical variables will be used. The self-reported sunscreen usage data will be dichotomized and analyzed by Chi-squared statistical test to establish whether sunscreen consumption will differ between the intervention and control groups. Two-sided *p*-values of <0.05 will be considered statistically significant and statistical uncertainty will be expressed using two-sided 95% confidence intervals. For the main study parameter, intention-to-treat analysis will be performed.

For the secondary study parameters we will present the levels of biomarkers and the number of sunburn episodes as quantitative, continuous variables. The biomarker levels at $T = 6$ weeks and $T = 12$ weeks will be compared with the baseline levels using paired ANOVA test followed by the correction for multiple testing, dependently on the distribution of data. The presence of NMSC including AK will be presented as counts and percentages.

UV-exposure measured by UV-dosimeters will be presented per job task, and as average of the measurements by all workers who worn the dosimeter in the same period. Data will be presented as average dose per day. Furthermore, the UV-exposure pattern during the work shift will be revealed.

The distribution will be tested by using Shapiro-Wilk normality test.

Before data analysis, a detailed data analysis plan will be available.

Blinding

Due to the study design and the placement of dispensers on the intervention work sites, it is not possible to blind the participants and investigators. The analysis of the SC samples will be performed blinded, the samples will be coded and the unblinding will be performed after all data are analyzed and archived in the laboratory.

DISCUSSION

The overall purpose of this study is to evaluate the effectiveness of an intervention comprising the facilitation of sunscreen dispensers and regular feedback on sunscreen use in outdoor construction workers. Next, this study will provide insight in UV-exposure, and prevalence of NMSC including AK in construction workers in the Netherlands.

The effectiveness of the intervention will be assessed from self-reported data on sunscreen use (primary outcome), and the changes in the levels of biomarkers of internal UV-dose measured at baseline and after 6 and 12 weeks (secondary outcome). To evaluate the process of the intervention, electronically monitored sunscreen consumption will be used. Furthermore, satisfaction regarding intervention and main barriers for using of sunscreens will be investigated in construction workers.

The intervention is easy and straightforward, and as such the expectation is, that it should be feasible to implement on construction sites. The results of this study will gain insight into the effectiveness of the intervention on UV-protection, and will provide relevant data on the use of sunscreen in outdoor work situations and on the occupational UV-exposure of construction workers.

Recently, a randomized control crossover trial in the United Kingdom (48) which aimed to reduce UV-exposure in the summer, found outdoor workers were exposed to relatively high UV levels in the summer. From the measured UV-dose, approximately a two-fold increase in the risk of being diagnosed with NMSC could be expected if the exposure continued their whole life. The intervention was based on increasing awareness by sending daily messages on the smartphone with recommendations for appropriate measures to reduce UV-exposure. However, this intervention failed to reduce exposure to UV (48). Another study in the United Kingdom found a slight (non-significant) change in sun protective behavior in construction workers after showing them an educational video (49). Our study is focused on reducing internal UV-exposure by using sunscreen. To remove possible barriers such as availability, accessibility, and the costs of sunscreen (10, 21, 22), we provide sunscreen dispensers placed at easily accessible places. Furthermore, we will electronically monitor the amount of sunscreen used, and provide regular feedback on sunscreen use by means of posters. In general, monitoring and feedback are widely used as a strategy to induce behavior change and have been shown to be effective when baseline performance is low, and it is provided more than once (50). Also group monitoring is recognized as being more effective than monitoring systems based on tracking individual actions which do not exploit the stimulating effect of group coherence (50). However, a recent systematic review found that there is very low quality evidence that company-oriented safety interventions reduce injuries among construction workers, and action is needed to increase the adherence of construction workers and employees to protection measures (51).

Strong points of this study are the real-time monitoring of sunscreen use, facilitation of sunscreens, feedback on sunscreen use, and the objective assessment of external and internal UV-dose by using, respectively UV-dosimetry and biomarkers of UV-dose. Also, assessment of the prevalence of NMSC including AK in outdoor workers by a physician will provide evidence on the prevalence of occupational skin cancer in construction workers.

A limitation of this study is the lack of randomization, which was not feasible. However, the intervention and control groups will be matched regarding same sample size, working environments, and job tasks. The risk of contamination bias is limited because the participants work on different and separated work sites, and therefore are not influenced by the other groups. However, we will give basic information on sun-safety and UV-protective behavior at the beginning of the study (baseline) in the control groups also, therefore this might lead to change in sun-protective behavior. Nevertheless, we cannot withhold basic information from the control groups for ethical reasons. The risk of recall bias cannot be entirely avoided because we use questionnaires to measure the primary outcome, however, we counteract by limiting the timeframe through asking questions concerning 1 month in the past. Lastly, it is known that the body location of the UV-dosimeter has an impact on the measured exposure (52). However, we use UV-dosimetry only on one body location (i.e., the upper left arm) because this is practicable for construction workers, and this is the same body location as a large European study (27) used which makes comparison of UV-exposure between our studies and other countries more feasible.

Study Status

Recruitment for this study had not started at the time of submission.

ETHICS STATEMENT

The study will be conducted in concordance with the principles of the Declaration of Helsinki (2013), and was approved by the Ethics Committee of Academic Medical Center, Amsterdam, the Netherlands (METC 2020_051/NL72818). Participation is voluntary and written informed consent will be obtained.

AUTHOR CONTRIBUTIONS

AK was largely involved in the conception, design, and operational management of the study, prepared the first version of the study protocol and manuscript, and will also be responsible for performing the clinical and biochemical assessments during the study. SK has expertise in skin bioengineering methods for the assessment of stratum corneum samples, involved in the conception, design, and supervision of the trial, and drafting the study protocol and the manuscript together with AK. HM brings expertise in occupational health, pragmatic research, translating research findings into policy, involved in the concept, design, and drafting of the study protocol and manuscript together with AK. TR brings in expertise in dermatology, pragmatic research, and critically reviewed the manuscript. CH brings expertise in occupational health, pragmatic research, and critically reviewed the manuscript. All authors read and approved the final manuscript.

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Health Risks Associated With Excessive Exposure to Solar Ultraviolet Radiation Among Outdoor Workers in South Africa: An Overview

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Exposure of outdoor workers to high levels of solar ultraviolet radiation (UVR) poses significant, well-known health risks including skin cancer and eye diseases. In South Africa, little is known about how many workers are potentially overexposed to solar UVR and what the associated impacts on their health might be. In this overview, the geography and solar UVR environment in South Africa are considered, as well as the different outdoor occupational groups likely to be affected by excessive solar UVR exposure. Sunburn, pterygium, cataract, keratinocyte cancers, and melanoma are discussed in the context of outdoor workers. Few studies in South Africa have considered these health issues and the most effective ways to reduce solar UVR exposure for those working outside. Several countries have developed policies and guidelines to support sun safety in the workplace which include training and education, in addition to the provision of personal protective equipment and managerial support. Several gaps in occupational sun protection and workplace sun safety for South Africa are identified. Legislation needs to recognize solar UVR exposure as an occupational health hazard, with sun safety guidelines and training provided for employers and employees.

Keywords: cataract, employment, environmental health, skin cancer, sun exposure, keratinocyte cancers, melanoma, personal sun safety

INTRODUCTION TO SOUTH AFRICA

Outdoor workers are particularly vulnerable to acute and chronic health risks from excess exposure to solar ultraviolet radiation (UVR) (1). The skin and eyes are the most common target organs. It is of considerable interest to assess the risk for outdoor workers in South Africa as this country is subtropical, has a multi-ethnic population and the UV Index can reach 13 in the summer months (a UV Index of 11+ is considered extreme) (2). In this overview, we undertook a systematic search initially mainly using PubMed with the terms "South Africa," "outdoor workers," "solar UV radiation"/"sun exposure," "skin diseases"/"eye diseases" and then each category of outdoor worker and each category of disease separately. References listed in related papers were also retrieved. We present the geography of South Africa and its climate, together with a summary of the population and outdoor worker groups. An account is then given of the ocular and cutaneous health risks associated with excess sun exposure of outdoor workers in South Africa, followed by studies examining sun protection. The final section considers actions needed to prevent the adverse health risks from excess sun exposure in the country.

TABLE 1 | Maximum, minimum and mean UV Index, sunshine hours and ambient temperature in summer and winter in Cape Town, Durban, and Pretoria (weather-and-climate.com; weather-atlas.com).

	Cape Town	Durban	Pretoria
Latitude	33.9°S	29.9°S	25.7°S
Altitude (m)	0–300	8	1,339
Summer temperature (°C)			
Maximum	26	28	29
Minimum	16	21	18
Mean	23	25	25
Winter temperature (°C)			
Maximum	18	23	19
Minimum	7	12	5
Mean	13	18	13
Summer sunshine hours			
Mean daily	10	6	8
Winter sunshine hours			
Mean daily	6	8	10
UV Index			
Summer	9–10	12	11+
Winter	2–3	4–5	4–6

GEOGRAPHY AND CLIMATE

South Africa is situated in the midlatitudes between 22°S and 35°S. Its topography comprises coastal plains and a large, central plateau, the Highveld, located in the interior of the country at about 1,200 m. Frequent high pressure over the plateau leads to relatively cloudless skies throughout the year which, together with the high altitude, contributes to high ambient solar UVR levels. **Table 1** shows the maximum, minimum and mean UV Index, sunshine hours and ambient temperature in summer and winter in Cape Town, Durban and Pretoria.

POPULATION GROUPS AND OUTDOOR OCCUPATIONS

Four groups formally delineate the population of South Africa, namely Black African, White, Indian/Asian and Coloured [mixed European (White) and Black African or Asian ancestry]. Of the 59.6 million population in 2020, 80% were Black African, 8% White, 3% Indian/Asian and 9% Coloured (3). The country is divided into nine provinces (**Figure 1**) with about 40% of the population residing in the four coastal provinces, Northern Cape, Western Cape, Eastern Cape and KwaZulu-Natal, and the largest percentage of the population (26%) living in the inland province of Gauteng.

About 14 million people of working age (18–65 years) are employed in all sectors in South Africa (4). Of these, approximately 4 million people work outdoors either in formal or informal jobs. About 250 000 people are employed in forestry, 150,000 in fishing, 885,000 in formal agriculture and 3 million in subsistence or household agriculture (5–8). It is not possible to determine exact numbers of people working outdoors in mining and construction since they may be underground and indoors, respectively for all or part of their employment. However, it is assumed that a considerable proportion of South African construction workers stay outdoors for at least part of their working day, as has been shown in a study based in Denmark (9). In addition, those working in surface, open-pit mines are likely to experience significant sun exposure. Out of approximately 92,000 employed as coal miners in South Africa in 2019, half worked in open-pit mines, and about one-third of the 95,000 working in gold mines (10).

Solar UVR exposure of outdoor workers has been measured for different occupations around the world with few studies carried out in South Africa. Construction workers in Australia were exposed to a daily dose of 10 standard erythemal doses (SEDs where 1 SED = 100 Jm^{-2}) (11). Farmers in Italy received on average 15 SED per day or about 80% of the ambient solar UVR (12). Similarly, a South African school groundsman/gardener was exposed to 80% (4 SED) of the ambient solar UVR per day (13) while farmworkers were exposed to 46% (8–12 SED) of the ambient solar UVR per day (14).

The factors influencing how much solar UVR an outdoor worker receives are environmental, including latitude, altitude, cloud cover, solar zenith angle, stratospheric ozone and albedo, and occupational relating to the type of work activity, length of time spent outside, and provision of physical sun protection infrastructure, such as shade (1). Individual factors include personal attitudes and sun protection used. In addition, skin phototype is an important parameter: those people with fair skin burn easily in response to solar UVR exposure and do not tan, while the presence of melanin in those with deeply pigmented skin offers protection against sunburn and other detrimental health aspects of solar UVR exposure (15, 16).

HEALTH RISKS ASSOCIATED WITH EXCESSIVE SOLAR UVR EXPOSURE AMONG OUTDOOR WORKERS IN SOUTH AFRICA

Several eye and skin diseases globally are associated with sunlight exposure. Some are classed as acute, becoming evident several hours after a high dose of solar irradiation. Details are provided below of acute conditions in both the eye and skin. Others occur as a result of chronic exposure to solar radiation. The major chronic sun-associated diseases in the eye are non-melanoma skin cancer (NMSC) of the lid and conjunctiva, ocular melanoma, cataract, pterygium, climatic droplet keratopathy (epithelial degeneration) and pinguecula (local degeneration of conjunctiva). The major chronic sun-associated diseases in the skin are NMSC and cutaneous melanoma (CM). Below, details are provided of pterygium, cataract, NMSC, and CM. It should be noted that epidemiological studies of these diseases in South Africa are rare but, considering the frequent high UV Index in this country, in association with warm temperatures, clear

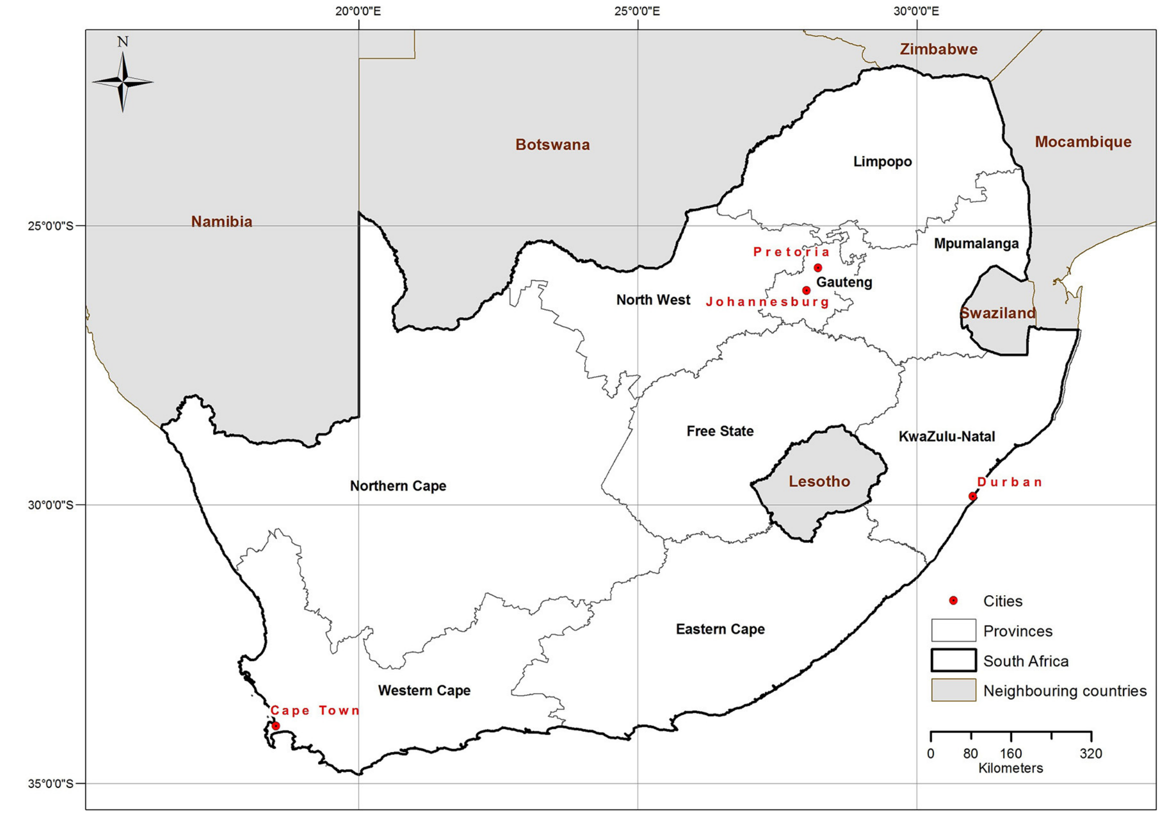

FIGURE 1 | Map of South Africa indicating the nine provinces and the four major cities.

skies and reflective terrain or water, it is likely that solar UVR-induced ocular and cutaneous damage occurs, which may present particular health risks in those who work outdoors.

ACUTE EFFECTS OF SOLAR UVR ON THE EYE AND SKIN

Sunburn is well-recognised following excessive sun exposure, with photoconjunctivitis (inflammation of the conjunctiva) and photokeratitis (inflammation of the cornea) on the surface of the eye also considered as sunburn. Individuals with fair skin are more susceptible to sunburn than those with pigmented skin; (16) indeed, it has been calculated that there is an approximate 10-fold increase in the erythemal sensitivity of white skin compared with black skin (17) but those in the latter category can still get sunburnt.

Rosenthal et al. estimated that an outdoor worker was likely to receive 10–70% of the total ambient daily solar UVR, depending on the time spent in the sun that day (18). A figure of 20% of the total daily ambient solar UVR, as measured by ground-based instruments, was converted into possible exposures of outdoor workers by skin type and season at two locations in South Africa, Durban (latitude 30°S) and Cape Point (34°S) (19). It was concluded that there was a risk of sunburn for outdoors workers in both sites throughout the year for all the ethnic South African populations, except in mid-winter for those with deeply pigmented skin. Finally, a pilot study, prompted by an increase in ambient temperatures associated with global warming, reported that those working outdoors in sun-exposed conditions in hot parts of South Africa experienced painful eyes and blurring of vision which may indicate ocular sunburn (20).

These reports, while few in number, do show the real possibility of outdoor workers in South Africa getting sunburnt on their eyes or exposed skin during the course of their work. This is of concern, not only for the immediate health of the individual but because such episodes, when repeated, are likely to increase the risk of skin cancer in later life (see sections below).

CHRONIC EFFECTS OF SOLAR UVR ON THE EYE

Pterygium

Pterygium is a wing-shaped invasive growth on the conjunctiva that frequently starts at the corner near the nose, causing the eye to feel itchy and burning. It can lead to extreme discomfort as it progresses and to blurred vision if it covers the pupil. Pterygium is one of the commonest eye disorders, with a mean age of development of 44 years. The population attributed factor of pterygium due to solar UVR exposure was calculated as 42–74% in 2006 and, as outdoor work is one of the relevant risk factors, the suggestion was made that pterygium should be considered as an occupational disease (21). The most recent meta-analysis regarding pterygium included 68 articles from 24 countries, although none from South Africa (22). Prevalence was estimated as 12% in the total population globally and slightly higher in men than in women. Exposure to sunlight was the major environmental risk factor with odds ratios of 1.24 for sunlight exposure longer than 5 h daily, 1.45 living in rural areas, 1.46 outdoor occupations and 0.47 if sunglasses were worn.

Few studies have been published which provide detailed information about pteryium in South Africa. Corneal diseases, mainly pterygium and climatic droplet keratopathy, were present in 20% of Coloured patients in a local community in northwest Limpopo (23). Angurin et al. proposed that exposure to sunlight could be a trigger for pterygium development in genetically predisposed Black Africans living in rural Limpopo province (24). In Ibadan, Nigeria, the prevalence of pterygium in patients attending an eye clinic was 9% with 65% of those being outdoor workers (25).

Cataract

There are three types of age-related cataract based on the location of the lens opacities: nuclear which is the most frequent, followed by cortical and then posterior subcapsular cataract, the least frequent. Epidemiological studies many years ago linked sunlight exposure and cataract development (26, 27). Subsequently exposure to solar UVR was recognised by the World Health Organization (WHO) as the major environmental risk factor for cortical cataract (21). A systematic review in 2018 discovered that 15 studies had been published between 1997 and 2017 in which the risk of cataract was evaluated in the context of outdoor work (28). Twelve of these showed a positive association between long-term occupational solar UVR and cortical cataract with some evidence for nuclear cataract too. A meta-analysis to enable a relative risk to be calculated was not possible as the design of each study was different, and the methods used to estimate occupational UVR exposure were not exact. Therefore, although no study has been carried out that monitors the risk of cataract development in outdoor workers in South Africa, there is sufficient evidence from many other countries to indicate that this is highly likely.

Cataract accounts for about 50% of cases of blindness globally and sub-Saharan Africa has the highest regional burden of blindness at 20% of the world's cases and only 11% of the world's population. The prevalence of self-reported cataract in South Africa was 4.4% from data collected in 2007–2008 (29). Early studies in South Africa showed an annual incidence of cataract blindness of 0.14% with a prevalence of 0.6% in a rural population in KwaZulu-Natal, (30) and cataracts were the cause of loss of vision in 60% of blind Black Africans in rural Northern Transvaal (31). In the only recent study on cataract based in South Africa, Khoza et al. estimated that the prevalence of cataract was 67.4% in those aged over 18 years living in rural villages in Vhembe district, Northern Limpopo (32). It is known that cataract formation begins earlier in African populations than in comparable populations in India and USA, (33) and that it is more common in rural than urban areas (34, 35).

CHRONIC EFFECTS OF SOLAR UVR ON SKIN

Non-melanoma Skin Cancers (NMSCs)

These comprise squamous cell carcinomas (SCCs) and basal cell carcinomas (BCCs), also called the keratinocyte cancers. Actinic (or solar) keratosis, which presents as a red scaly patch on sun exposed body sites, is considered an early *in situ* form of SCC. Both BCCs and SCCs are disfiguring and debilitating, with SCCs occasionally becoming invasive and life-threatening if left untreated. NMSCs have the highest incidence of any cancer in Caucasian populations (35). They occur in people of all skin colours but particularly in those with fair skin as the high content of cutaneous eumelanin in pigmented skin provides substantial protection, estimated as 13-fold in African Americans compared with the White American population (36).

Exposure to solar UVR is the major environmental risk factor for both BCC and SCC (37). Intermittent high solar UVR exposures, especially in childhood and adolescence, together with chronic exposure, promote the development of BCCs; cumulative life-time exposure promotes the development of SCCs (38). In the context of outdoor workers, it should be noted that using data obtained from personal UV exposure may provide a more valid association with the risk of skin cancer development than relying on occupation title as a proxy.

In South Africa in 2000–2004, the age-standardised annual incidence of BCC per 100,000 was 3.0 and 1.7 in Black African men and women respectively, and 198 and 113 in White men and women respectively, while the incidence of SCC was 3.0 and 1.6 in Black African men and women respectively, and 70 and 32 in White men and women respectively (39). BCCs in people of all skin colours occur predominantly on sun-exposed body areas and on the back. SCCs in Black Africans develop mainly on the lower limbs but in Whites are found on body sites most exposed to the sun, such as the face and backs of the hands. As the diagnosis of NMSCs in South Africa is made solely on the basis of histological findings, under-reporting is certain as local treatment of lesions is often undertaken without first collecting biopsies or individuals do not recognise their own skin tumours. Thus, it is difficult to detect trends in incidence although the number of cases per year globally has increased markedly in recent years and South Africa has probably followed this trend, at least in the White population group.

Regarding the effect of solar UVR on the risk of NMSC in outdoor workers, no reports based in South Africa have been published. However, there is compelling evidence from a systematic review and meta-analysis that included 18 studies based in various locations in Europe, North America and Australia (40). There was an increased risk of SCC in those with occupational solar UVR exposure compared with those not having occupational solar UVR exposure: the odds ratio was 1.77. Furthermore, the strength of the association increased with decreasing latitude and thus higher ambient solar UVR. In a similar fashion, the relationship between BCC in outdoor workers and solar UVR was analysed in another systematic review and meta-analysis (41). There was a 40% increased risk of BCC in outdoor workers compared with indoor workers or the general public, and a strong inverse relationship between occupational solar UVR exposure and BCC risk with latitude. Recent studies have indicated that actinic keratoses are twice as common in those who worked outdoors in Denmark compared with indoor workers, (9) and that outdoor workers in Italy had a significantly higher incidence of NMSC or actinic keratosis than those with no outdoor work (42).

Despite the lack of direct evidence from South Africa and especially when the frequent high UV Index allied with hot temperatures may make wearing sun protective clothing less likely, it would be astonishing if there was not a considerable risk of outdoor workers developing NMSC and actinic keratosis, although Black Africans will be at lower risk than their White counterparts due to their pigmented skin.

Cutaneous Melanoma (CM)

CMs are the least common of the skin cancers in people with fair skin but generally outnumber BCCs in those with pigmented skin. CMs account for more than 80% of deaths from skin tumours with late presentation and a more aggressive course in pigmented compared with fair skin (36). CMs occur most frequently on the backs of men, the legs of women and sun exposed body sites in the elderly in those with fair skin, (43) while they present mainly as acral lentigenous lesions on the palms of the hands, soles of the feet and around nails in those with pigmented skin (44). A survey in 2020 covering 31 countries, although none in Africa, found a general increase in the incidence of CM and mortality since the 1960s, especially in men, with an indication that these rates may be stabilising in the past decade in younger birth cohorts (45).

Data from the National Cancer Registry of South Africa showed that the age-standardised incidence per year of CM between 2005 and 2015 per 100,000 people was 0.5 in the Black African population and 23.2 in the White population, (46) thus demonstrating the protection offered by eumelanin in pigmented skin as one factor explaining the substantial difference in incidence (47). Over 800 deaths from CM were registered in South Africa in 2016 (48). Although the lack of a comprehensive population-based death registry in South Africa limits an accurate assessment of trends in CM mortality, an increase of about 3% in the White population between 1999 and 2014 was estimated, with no change in the Black African population (49).

Exposure to solar UVR as a risk factor for CM is complex. In people with fair skin, a dual pathway has been proposed whereby naevi, initiated by early sun exposure and promoted by intermittent high sun exposure thereafter, represents one route, and chronic sun exposure in sun-sensitive individuals represents a second route (50). As the majority of CMs in Black Africans develop on sun-protected body sites, risk factors other than direct solar irradiation are likely although these have not been identified. Indeed, a recent systematic review concluded that solar UVR is not an environmental risk factor for CM in people with skin of colour (51).

In contrast to the diseases outlined in the sections above, there is little evidence to indicate that outdoor workers, even with fair skins, have a higher risk than indoor workers or the general population of developing CM. A WHO Environmental Burden of Disease review included eight studies on the association between occupational sun exposure and CM, with only one of these reporting a positive relative risk for outdoor compared with indoor workers (21). Very recently a large cohort study based in Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) assessed occupation and socioeconomic status with the number of CM cases during 1961–2005 (52). It was calculated that both men and women with outdoor work were at significantly lower risk of developing CM than those with indoor work. This was attributed, at least in part, to workers with very fair skin or with a known genetic risk of CM being less likely to be employed in outdoor occupations.

In brief, there is little or no evidence to link outdoor work with an increased risk of CM, irrespective of skin colour.

SUN PROTECTION STUDIES

The WHO has identified solar UVR as a hazard in the workplace (53) and recommends protecting workers from excess solar UVR exposure (54). Personal protective measures for people working outdoors are clothing, hats, sunscreens, eye protection and shade (54). The Ultraviolet Protection Factor (UPF) and Sun Protection Factor (SPF) were developed to assure users of the sun protection capabilities of clothing/hats and sunscreen, respectively. Typical methods of sun protection for outdoor workers include avoiding exposure to direct sunlight around midday, seeking shade, wearing clothing with high UPF, hats with broad brims as well as helmets with neck flaps, and eyewear with wrap-around design or side panels, applying broad-spectrum sunscreen with a SPF of at least 30 to all exposed body sites, and avoiding any unnecessary elective UVR exposure, such as from sunbed use (54).

A review in 2007 included 14 descriptive studies of sun exposure and sun protective behaviours in outdoor workers based mainly in USA and Canada (55). Preventive practices were variable but generally ineffective. Men were more likely than women to wear hats and protective clothing, but women were more likely to use sunscreen. Another review of 34 descriptive and 18 intervention studies of farmers, construction workers and aquatic personnel in USA, Canada and Australia revealed that occupational UVR exposure limits were frequently exceeded. Inadequate protective behaviour led to high sunburn rates (56).

With regard to South Africa, a survey of farm workers in Limpopo province found that 80% never wore sunglasses and 23% never wore a hat when working (57). When a hat was used, peak caps were preferred to broad-brimmed hats although the latter provided better sun protection. Farm workers in Upington in the Northern Cape province wore long-sleeved overalls as their uniform rather than for sun protection and complained that they felt extremely hot during warm weather (58). Forestry workers in the Western Cape protected their faces from the sun using a variety of substances including ochre, clay and ordinary hand lotion, along with broad-brimmed and hard hats (58).

It is important that sun protective measures used by workers should not impair or pose a hazard to their ability to conduct work tasks. Provision of sails and awnings for shade are important physical barriers against solar UVR exposure. For example, canopies and awnings may provide adequate sun protection. For workers trading in an informal street market in KwaZulu-Natal, portable shade in the form of gazebos and canopies was the most common form of sun protection (59).

A critical determinant affecting the uptake of sun protection relates to personal knowledge, attitudes and behaviours. However, although outdoor workers in Germany knew about the risks of excess sun exposure, how to protect themselves, and what the UV Index means, such knowledge did not translate into sun protection uptake (60). Sunscreen application can be inappropriate and clothing uncomfortable or hinder the ability to conduct work tasks (61). Only one study in South Africa has considered knowledge and attitudes toward sun protection. Forestry workers in the Western Cape were aware of the risks of excess sun exposure but reported that they preferred not to use sunscreen because it was expensive and perceived to attract bees (58). Workers removed clothing when they felt hot, regardless of sun exposure, and chose not to use UVR protective goggles because they led to difficulties in seeing where to walk. Female workers wore broad-brimmed hats under their hard hats, while male workers had not been granted permission by the employer to do so (58). Female municipal gardeners working in Groblershoop in the Northern Cape wear broad-brimmed hats and protective clothing while working outdoors (**Figure 2**).

FIGURE 2 | Outdoor workers wearing broad-brimmed hats and protective clothing in Groblershoop, the Northern Cape.

ACTIONS NEEDED TO AMELIORATE THE ADVERSE HEALTH RISKS OF EXCESS SOLAR UVR EXPOSURE POLICY/GUIDELINES

Several standards exist to limit artificial UVR exposure, such as the American Conference of Governmental Industrial Hygienists (ACGIH) limit, (62) the International Commission on Non-Ionizing Radiation Protection (ICNIRP) limit (63) and the Australian Radiation Protection Standard (64). However, no standards exist to limit solar UVR exposure of outdoor workers, probably due to the variability of solar UVR environments, behavioural effects and anatomical exposure geometry (65). The WHO in collaboration with ICNIRP and the International Labour Organization advocate protection of workers from solar UVR (54) and Australia has adopted similar occupational sun protection guidelines (65).

In Victoria, Australia, under state occupational health and safety legislation, it is considered a requirement that employers protect workers, including contracted and causal employees, from solar UVR exposure (66, 67). To ensure a safe UVR environment employers should have a solar UVR protection policy or guidelines in place stating control measures that are endorsed by senior management. They should provide information and training about solar UVR protection and provide solar UVR protection/control measures for employees. These include shade, modifying reflective surfaces, rescheduling outdoor programmes to avoid periods of high solar UVR and providing personal protective equipment, such as broad-brimmed hats, sunglasses, sunscreen and sun-protective clothing. Employees must co-operate with their employers' efforts to ensure protection from excessive sun exposure. Similarly, in Canada, the Occupational Health and Safety Regulations state that the employers should provide skin protection to their employees and make sun safety information prominent in the workplace (68).

Uptake of sun protection by outdoor workers, when sun protection policy/guidelines do not exist, is generally poor (69, 70). In the mining sector, risk assessments (71, 72) are conducted and some include consideration of exposure to solar UVR and provisions of recommendations for exposure management and protective measures.

However, in general, in South Africa there are no national policies or guidelines for employers on how to protect outdoor workers from excess solar UVR exposure nor the most effective methods for the employees to protect themselves. This gap needs to be addressed by first amending the Occupational Health and Safety Amendment Act (No. 181 of 1993) (73) to include solar UVR exposure as an occupational risk. The National Institute for Occupational Health together with the Cancer Association of South Africa (CANSA) would be appropriately positioned to draft workplace sun safety guidelines that present the case for sun protection at work, important facts about solar UVR, mechanisms to protect workers from adverse sun exposure impacts, and health surveillance in the workplace (74). Guidelines should follow those recommended by the WHO (53) and should include at least the following sections:

- A description of what solar UVR is and why it is a hazard in the workplace;
- The health risks associated with exposure to solar UVR in the workplace, including effects on the skin and the eyes;
- How to manage the risks associated with excess solar UVR exposure in the workplace using several measures including:
  - Engineering controls: e.g., shade cover.
  - Administrative controls: e.g., rescheduling outdoor work programmes to avoid peak solar UVR hours.
  - Personal protective equipment: e.g., hard hats with neck flaps, sunglasses.
  - Training: e.g., on the risks of excess exposure to solar UVR and what is expected of employers and employees while at the workplace to minimize the risks.
- What to do if workers have been overexposed, i.e., to seek medical attention.

These generic guidelines should be tailored for different sectors and types of outdoor work, as well as for geographic location which influences solar UVR intensity (2) and workplace culture (70) to ensure commitment and uptake by outdoor workers. The South African Institute of Occupational Safety and Health (Saiosh) is the membership body which could assist with knowledge dissemination of the proposed guidelines as well as training of occupational hygienists on sun protection in the workplace.

EMPLOYEE/EMPLOYER EDUCATION AND TRAINING

The UV Index is a tool that can be used by outdoor workers to understand when solar UVR levels are deemed to be risky; sun protection is required when the UV Index is 3 or greater (2). A UV Index of 3–5 (moderate) calls for taking precautions when outdoors such as covering up, using sunscreen and staying in the shade the during midday hours. When the UV Index is high (UV Index 6–7) workers are advised to adjust their work schedules to avoid exposure between 11 h and 16 h and use sun protection, i.e., clothing, hat, shade, sunglasses, and sunscreen. Very high (UV Index 8–9) and extreme (UV Index 11+) values call for workers who must work outside to take all precautions since unprotected skin and eyes can burn quickly.

Several countries have developed training materials for occupational sun protection including the Health and Safety Agency in the United Kingdom, (75) the Australian Radiation Protection and Nuclear Safety Agency, (76) and the United States Department of Labour (77). Safety, Health, Environment and Quality (SHEQ) training should include information about relevant health risks and the need to protect the eyes and skin. When policy/guidelines, educational interventions and sun protection are implemented in the workplace, there is strong evidence that skin cancer and other solar UVR exposure-related health risks in outdoor workers can be reduced (78).

In summary, the South African Occupational Health and Safety Amendment Act (No. 181 of 1993) (73) provides for workers' rights to a safe and healthy occupational environment. However, there is no specific legislation regarding solar UVR exposure for outdoor workers (such as those engaged in agriculture, forestry or construction) in South Africa. Moreover, little attention is paid to occupational health in the country's climate change and health adaptation plan (79). South Africa needs to amend its occupational health and safety legislation by acknowledging solar UVR exposure as an occupational risk. Is also needs to consider developing and implementing sun safety guidelines and training modules that inform workers and employers about the health risks associated with excessive sun exposure in the workplace and appropriate sun protection measures.

CONCLUSION AND RECOMMENDATIONS

Due to high ambient solar UVR levels throughout much of the year in South Africa, there is the potential for an increased risk of several eye and skin diseases in outdoor workers. Although few studies have examined this possibility in South Africa, strong evidence from round the world has been obtained. Detailed results are discussed which demonstrate the association between solar irradiation and an increased incidence of acute sunburn of the eyes and skin, and of the chronic conditions, pterygium, cataract and skin cancer in those who work outdoors compared with indoor workers or the general population. Future research in South Africa should determine solar UVR-associated health impacts among workers in different sectors, especially for the skin and eyes.

Sun protection is an effective way to reduce solar UVR exposure for those working outside. Several countries have developed policies and guidelines to promote sun safety in the workplace. These include training, personal protective equipment and managerial support. In South Africa, legislation is needed to recognise solar UVR exposure as an occupational health hazard, with sun safety guidelines and training provided for both employers and employees.

LESSONS LEARNED

- South Africa experiences high solar ultraviolet radiation levels that pose health risks.
- Outdoor workers are at risk of high personal sun exposure that may affect their eyes and skin.
- South African policy and/or legislation needs to recognise sun exposure risks for workers.
- Employers and employees should apply appropriate sun protection measures.

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Knowledge, Attitudes, and Practices of Military Personnel Regarding Heat-Related Illness Risk Factors: Results of a Chinese Cross-Sectional Study

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Background: Military personnel are widely exposed to risk factors for heat-related illnesses. Knowledge, attitudes, and practices (KAP) are three of the most important means by which to prevent such illnesses, but there has been a lack of investigations into and correlation analyses of KAP. This study aimed to explore the heat-related KAP of military personnel in China.

Methods: We conducted a cross-sectional study (June 1-25, 2019). A total of 646 military personnel were recruited from two Chinese Navy troops in the tropical zone and one troop in the temperate zone. We collected data on demographic characteristics and KAP scores using questionnaires. Univariate analysis and Scheffe's method were used for data analyses.

Results: The mean KAP scores were 10.37 (range = 3–13, standard deviation = 1.63) for knowledge (K-score), 7.76 (range = 0–16, SD = 2.65) for attitudes (A-score), and 3.80 (range = 1–6, SD = 1.12) for practices (P-score). There were noticeable differences in mean K-score according to age, military rank, and educational level ($P < 0.05$). Participants from the tropical zone had higher A-scores ($P < 0.05$) and higher P-scores ($P < 0.001$) than those from the temperate zone. Additionally, participants with relevant experience also had higher A-scores ($P < 0.05$) than those without such experience.

Conclusions: Military personnel's awareness of preventive and first-aid measures against heat-related illnesses need to be strengthened. It will be very important to develop educational programmes and enrich systematic educational resources to raise this awareness.

Keywords: heat wave, heat-related illness, military personnel, China, knowledge, attitude, practice

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HIGHLIGHTS

- Since military personnel are widely exposed to risk factors for heat-related diseases, and this is the first time that the Chinese Navy has investigated KAP for heat-related diseases, research on this population may be of great significance.
- Military personnel scored highly on most common-sense questions about heat-related illnesses,but the accuracy rate of questions about exertional heat stroke were extremely low.
- Some misinformation related to media consumption with commercial purpose may be fatal at the critical moment for rescuing severe exertional heat stroke patients.
- The majority of respondents had good awareness of heat-related illnesses,and those from the humid tropical zone had higher mean A-scores than the temperate zone.
- Pearson's correlation coefficient indicated a weak correlation between the A- and P-scores.

BACKGROUND

The Intergovernmental Panel on Climate Change (IPCC) projects that the frequency, duration, and intensity of extreme weather may increase in the coming decades (1). A heat wave (HW) is a natural hazard characterized by an episode of hot weather. However, there is currently no universally accepted definition of HWs around the world in different fields. Especially in the military system, various definitions are employed (2). Thus, given this divergence, this study adopted the definition of three or more consecutive days with a maximum temperature over 35°C as published by the Chinese Meteorological Administration (3). The frequency of heat waves has increased in most parts of Asia (4), Europe (5, 6), and Australia (7, 8). Furthermore, heat waves can have significant effects on health and present a challenge for occupational-health protection. Heat-related illnesses include heat stroke, heat exhaustion, rhabdomyolysis, heat spasm, heat syncope, and heat rash. The inverse effects of heat-related illnesses on mortality have been widely reported. Mortality from heat stroke among the elderly exceeds 50% (9). Another study, conducted in 66 cities in China, showed that 5.0% of excess deaths may be associated with heat waves (10). The estimated number of heat-related deaths worldwide is expected to increase to 90,000 annually in 2030 and more than 255,000 in 2050 (11). Therefore, more attention should be paid to the insidious health effects of heat-related illnesses.

Risk factors associated with heat-related illnesses may be environmental or individual. Environmental risk factors, also known as exogenous factors, may include high temperatures, high humidity, and direct sun exposure. Individual risk factors, also known as endogenous factors, may include insufficient fluid intake, physical exertion, overall physical condition, medications, and pregnancy (12). Military personnel, especially those at low latitudes, where soldiers routinely experience high levels of physical exertion under high ambient temperatures and high humidity, are widely exposed to both exogenous and endogenous risk factors for heat-related illnesses. Military endeavors in heat wave conditions can alter the judgement and physical performance of military personnel, leading to significant impairment of individuals' ability to work, possibly even leading to death (13, 14). Therefore, reducing heat-related illnesses is a key factor in ensuring the combat effectiveness of the military during heat waves.

The purpose of knowledge, attitudes, and practices (KAP) surveys is to collect data on the knowledge, perceptions, and behaviors of specific populations in relation to a certain topic. The literature shows that knowledge of heat waves, attitudes toward risk factors, and adaptation practices are three of the most important factors in preventing heat-related illnesses (15). These findings could merely be local indicators that are representative of a particular field. KAP studies on heat-related illnesses have been performed among the general public for different occupations, and it is reported that several factors influence public KAP, such as age, educational level, economic level, nationality, and gender (16–18). However, only a few studies have focused on knowledge of heat-related illnesses among Chinese military personnel. There is a lack of investigations and correlation analyses of knowledge, attitudes, and practices. Therefore, in this study, we selected three Chinese naval troops with different risk factors that were working at low latitudes to explore the heat-related KAP of military personnel for the first time. Our aim was to provide data for future policy formulation and implementation in response to heat waves and associated side effects.

METHODS

Study Area and Participants

A total of three naval troops took part in the study. Two of these troops were stationed in the tropics (∼9° north latitude), where they worked in a high-temperature and high-humidity environment all year round. The hottest month (in terms of average maximum temperature) was May (32°C). The month with the lowest average temperature was January (26.1°C); the wettest month (with the most rainfall) was September (251.4 mm), and the driest month (with the least rainfall) was January (8 mm). The month with the longest sunshine duration was June (average sunshine duration: 13.2 h). The month with the shortest sunshine duration was December (average sunshine duration: 11 h). The other sampled troop was stationed in a warm, temperate, continental monsoon climate zone (∼30° north latitude). The hottest month (with the highest average temperature) was July (28°C). The month with the lowest average temperature was January (−12.4°C). The wettest month (with the most rainfall) was July (128.8 mm). The driest month (with the least rainfall) was January (1.5 mm). The month with the longest sunshine duration was June (average sunshine duration: 15.9 h). The month with the shortest sunshine duration was December (average sunshine duration: 8.6 h). The geographical location and climatic characteristics of the three troops mentioned above was shown in **Figure 1**.

We used convenience sampling to select military personnel from these three naval troops. The target population of this study was active-duty sailors without experience working in health care. A platoon is a military unit containing 30–50 sailors. We included a total of 15 platoons of troops in the tropical zone,

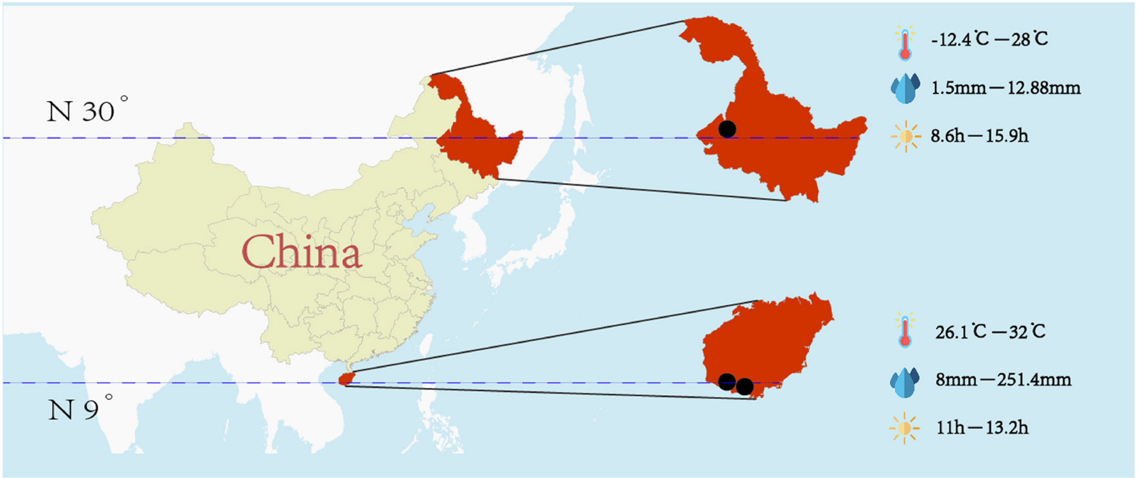

FIGURE 1 | Geographical location and climatic characteristics of the three sample troops.

including 560 sailors in total, in this study. In the temperate zone, we included three platoons with a total of 86 sailors.

Data Collection

We developed a questionnaire based on a review of the literature on heat waves and heat-related illnesses (**Supplementary Material 1**). The questionnaire "Research Questionnaires on knowledge, attitude and practice toward heat-related illnesses during field training exercises" was initially drafted in English by Li Gui and Sarathchadra, and was translated from English to Chinese by Demeng Xia, Xuren Wang, and then was translated then back to English by Yixin Wang, Xisha Long to ensure the meaning of the content. The questionnaire consisted of four sections: (1) sociodemographic information, including age, years of military service, educational level, marital status, military rank, and heat-related illnesses experience; (2) the knowledge (K) section including 18 items on clinical symptoms, treatment, risk factors, prevention and control of heat-related illnesses (13 true–false items and five multiple-choice items); (3) the attitude (A) section including four items about attitude of sailors toward heat-related illnesses; and (4) the practice (P) section including six items related to practices and behavior of heat-related illnesses prevention.

In the K section, participants received one point for answering each true–false item or multiple-choice question correctly; incorrect answers received zero points, with high scores indicated better knowledge of heat-related illness risk factors. Items in the A section were scored on a four-point scale, a high score indicates a positive attitude. The scale used Cronbach's α to assess internal reliability. Cronbach's alpha coefficient is 0.73, indicating internal reliability. The P section consisted of yes-or-no questions, with each "Yes" response earning one point and each "No" response earning zero points. The score ranges for the K, A, and P sections were 0–18, 1–16, and 0–6, respectively.

This cross-sectional quantitative survey collected data face-to-face using the time of regular assembly from 1 June 2019, to 25 June 2019. Well-trained researchers interviewed participants using the structured questionnaires, and respondents were informed that all information and opinions provided would be anonymous and confidential. Various actions were taken to ensure questionnaire quality. First, a panel of experts was consulted at the development stage, and then a pilot study including only a few sailors was carried out for semantic analysis. Before the survey, all the researchers were systematically trained in the unified interview guide and questionnaire instructions. All questionnaires were completed and collected immediately to increase the response rate. Two independent researchers performed data collation and entry to minimize errors in data processing.

Data Analysis

We used SPSS for Mac software version 25.0 (IBM Corp., Armonk, New York, US) for data analysis. Mean and standard deviation (SD) values were calculated for continuous variables; categorical variables are expressed as the percentage of subjects. We used univariate analysis of variance to test the associations of each demographic characteristic with K-, A-, and P-scores and the overall score. Scheffe's method was used in further paired comparisons if necessary. Finally, we used Pearson's correlation coefficient to clarify the correlations between K-, A-, and P-scores. $P < 0.05$ was considered statistically significant.

Ethical Considerations

The study was approved by the Ethics Committee of the Institutional Review Board of the Naval Medical University, Shanghai, China (NMUMREC-2021-022). Written informed consent was obtained from all participants before the survey. All data obtained were anonymous.

RESULTS

Participant Demographics

In the baseline survey, a total of 646 subjects were approached and invited to join this study. However, six of them did not complete the questionnaires, leaving 640 (99.1%) in the final

TABLE 1 | Demographic characteristics (*n* = 640).

Characteristic	Category	*n*	Proportion (%)
Age (years)	≤20	59	9.2
	21–25	347	54.2
	26–30	154	24.1
	≥30	78	12.2
	Unanswered	2	0.3
Years of military service	≤1	48	7.5
	1–5	281	43.9
	6–10	159	24.8
	11–15	107	16.7
	≥16	44	6.9
	Unanswered	1	0.2
Education level	Bachelor level or above	139	21.7
	Junior middle school	214	33.4
	Senior middle school	253	39.5
	Elementary school	31	4.8
	Unanswered	3	0.5
Marital status	Unmarried	479	74.8
	Married	157	24.5
	Divorced	2	0.3
	Unanswered	2	0.3
Rank	PFC	90	14.1
	Corporal	206	32.2
	Sergeant or above	248	38.8
	Junior officer	76	11.9
	Field officer	17	2.7
	Unanswered	3	0.5
Climate zone	Tropical zone	556	86.8
	Temperate zone	84	13.2
Heat-related illness experience	Yes	186	29.1
	No	453	70.8
	Unanswered	1	0.2

analysis. Their sociodemographic characteristics are presented in **Table 1**. All participants were male, and their mean age was 25.1 years (range = 18–43 years, SD = 4.09). The greatest share of participants (43.9%) had been in military service for 1–5 years. Educational levels and military ranks varied. Of all participants, 86.8% were stationed in the tropical zone, and 29.1% had heat-related illness experience.

Response to Questions on Knowledge

Table 2 details the responses showing participants' knowledge about heat-related illnesses. More than half of the true–false questions received correct answers from >80% of respondents. Most participants (95.9%) were familiar with heat exhaustion management, including transferring victims to a cool environment; drinking fluids; and using cool water, ice packs, and fanning. However, over one-third of participants (34.7%) did not know that sweating could reduce body temperature, and 37.5% of participants thought that only physically weak persons were susceptible to heat-related illnesses during field training exercises. Moreover, 81.2% of participants deemed that heat exhaustion is characterized by a body temperature higher than 40°C, which showed that most participants did not have basic knowledge of heat stroke. The multiple-choice items received far fewer correct answers than the true–false items did. Alcohol was considered by 77.4% of participants to be the best means of decreasing health risks from heat waves, when actually it is a risk factor. The World Health Organization (WHO) recommends drinking water or using oral rehydration salts (ORS) (19), but 85.0% of participants said that they preferred to drink soda during field training exercises.

Responses to Questions on Attitudes and Practices

In the attitudes section, only 26.2% of participants said they were very concerned about the risks of heat-related illnesses. Additionally, 40.4% reported they were somewhat sensitive to heat-related illnesses, whereas <12.8% said they were "not at all" sensitive. In the practices section, most participants (79.7%) reported that when a high-temperature alert was released, their leaders generally arranged outdoor activities at relatively cooler times, and medics took intervention measures (74.4%). Additionally, 71.9% of participants were aware that it is necessary to implement good preventive measures against heat-related illnesses. However, only 64.8% of participants had received health education prior to field training, and nearly three-quarters of participants (74.4%) said that they drank water only when they were thirsty (**Table 3**).

Mean Scores for Knowledge, Attitudes, and Practices

Detailed mean KAP scores and mean overall scores according to demographic characteristics are shown in **Figure 2**. The mean K-score was 10.37 (range = 3–13, SD = 1.63). There were noticeable differences in mean K-score according to age, military rank, and educational level ($P < 0.05$). Paired comparisons using Scheffe's method indicated that the mean K-score was lower among participants <20 years old compared with the other age groups ($P < 0.05$) and higher among junior officers ($P < 0.05$) and participants who had at least a bachelor's degree ($P < 0.05$).

The mean A-score was 7.76 (range = 0–16, SD = 2.65). Participants from the tropical zone had higher A-scores than those from the temperate zone (8.2, SD = 3.08 vs. 6.9, SD = 2.34; $P < 0.05$). Participants with heat-related illness experience had higher A-scores than those who did not have such experience (7.8, SD = 2.65 vs. 6.9, SD = 2.58; $P < 0.05$).

The mean P-score was 3.80 (range = 1–6, SD = 1.12). Participants from the troops stationed in the tropical zone had higher P-scores (4.3, SD = 0.90 vs. 3.6, SD = 1.22; $P < 0.001$) than those from the temperate zone.

Correlations Between Knowledge, Attitudes, and Practices

Correlation analyses suggested a significant positive correlation between A- and P-scores ($r = 0.170$, $P < 0.001$). No positive correlation was found between K- and A-scores or between K- and P-scores (**Table 4**).

TABLE 2 | Responses to knowledge items ($n = 640$).

	Question	Category	*n* (%)
Yes or No responses	1. Could fainting and collapse be due to heat-related illnesses during field training exercises?	Yes[a] No	84.1 15.9
	2. Is heat exhaustion managed by transferring the victim to a cool environment, drinking fluids, and applying cool water, ice packs and fanning?	Yes[a] No	95.9 4.1
	3. Are fever, fatigue, and chest tightness common symptoms of heat stroke?	Yes[a] No	80.1 19.1
	4. When heat stroke is suspected, should you first transfer the victim to a cool environment and then ask for an ambulance?	Yes[a] No	93.2 6.8
	5. Can wearing thick clothes prevent heat stroke?	Yes No[a]	5.5 94.5
	6. Could the victim's muscle cramps be caused by heat-related illnesses during field training exercises?	Yes[a] No	81.8 18.2
	7. Can cooling the body down prevent heat stroke?	Yes[a] No	86.5 13.5
	8. Can staying in cold spots prevent heat stroke?	Yes[a] No	93.3 6.7
	9. Is dehydration one of the symptoms of heat stroke?	Yes[a] No	92.2 7.8
	10. Can sweating lower body temperature?	Yes[a] No	65.3 34.7
	11. Are only physically weak persons susceptible to heat-related illnesses during field training exercises?	Yes No[a]	37.5 62.5
	12. Can heat-related illnesses cause a rapid loss of the victim's life during field training exercises?	Yes[a] No	84.0 16.0
	13. Is heat exhaustion characterized by a body temperature higher than 40 degrees?	Yes No[a]	81.2 18.8
Multiple-choice responses	1. Please select the symptoms or signs of heat-related illnesses that you consider to be severe during a field training exercise	No sweating[a] Sweating Fainting Fatigue	25.2 78.2 38.8 20.5
	2. Which drink would you prefer for a heat victim during field training exercises?	Ginger drink Soda drink Water and ORS[a] Coffee	40.3 85.0 36.8 22.7
	3. Which of the following factors increases the risk of heat-related diseases	Aging Overweight Alcohol Sufficient fluid intake[a]	21.6 29.2 77.4 9.7
	4. How can a person prevent heat-related illnesses during field training exercises?	Alcoholic beverages Enough water[a] Wearing thick and dark clothes Using sunscreen	93.4 14.4 40.5 38.9
	5. Which type of heat-related illnesses is the most serious?	Heat cramp Heat exhaustion Heat stroke [a] Heat syncope	60.3 70.5 37.5 73.4

[a] *The correct answer.*

DISCUSSION

Several studies have reported that heat waves have adverse effects on human health (19). People's awareness of the risks of, knowledge about, and protective practices against heat-related illnesses are crucial elements in reducing the harmful health effects of heat waves (20). However, to the best of our knowledge, this is the first study to survey KAP of heat-related illnesses in

TABLE 3 | Responses to attitude and practice items (*n* = 640).

	Question	Category	*n* (%)
Attitude	1. Do you intend to take preventive measures against heat cramps, heat exhaustion and heat stroke before and during field training exercises if a high-temperature warning is released?	Very much	45.1
		Much	42.4
		Sometimes	8.6
		Not at all	4.0
	2. How much do you worry about the risk of heat-related diseases in field training?	Very concerned	26.2
		Little concern	44.5
		Not at all	21.8
		I don't know	7.5
	3. Do you consider yourself sensitive to extreme heat?	Very much	34.7
		Somewhat	40.4
		Not at all	12.8
		I don't know	12.1
	4. Do you think the medics raise enough awareness for extreme heat?	Too much	30.3
		Just enough	40.4
		Too little	20.1
		I don't know	9.1
Practice	1. Will your leaders generally arrange outdoor activities at a relative cooler time when a high-temperature warning is released?	Yes	79.7
		No	20.2
	2. Before you go out for field training exercises, does your medics tell you how to prevent and cope with heat-related illnesses?	Yes	64.8
		No	35.2
	3. When you go out for field training exercises, do you implement good heat-related illnesses preventive measures?	Yes	71.9
		No	27.9
	4. During field training exercises, do you pay more attention to the signs and symptoms of heat cramps, heat exhaustion, and heat stroke?	Yes	63.1
		No	36.9
	5. Do you drink water only when thirsty during field training exercises?	Yes	74.4
		No	25.4
	6. When your troops go out for field training exercises, do medics prepare good heat-related illnesses intervention measures, such as medications, fluids and temperature-decreasing devices?	Yes	74.4
		No	25.4

the Chinese Navy. Studies on this population could be greatly significant, as military personnel are widely exposed to risk factors for heat-related illnesses. Therefore, the findings of this study might provide essential references for the training and health education of military personnel.

In this survey, the majority of participants had high scores for most K-related questions and demonstrated good awareness of and protective practices against heat-related illnesses. However, some subgroups showed lower K-, A-, and P-scores based on demographic factors, environmental differences, and personal experiences.

Knowledge plays an important role in mitigating the adverse effects of heat waves (2). By analyzing participants' answers to K-questions in this study, we found that military personnel scored highly on most common-sense questions about heat-related illnesses (e.g., 95% of participants knew that being in a cool environment; drinking fluids; and applying cool water, ice packs and fanning were interventional measures against heat-related illnesses). However, the accuracy rate of questions about exertional heat stroke were extremely low. Only 37.5% of participants recognized the severity of exertional heat stroke, and only 25.2% of participants considered not sweating to be a danger sign. Exertional heat stroke is a medical emergency that is directly related to strenuous physical activity. Military personnel in high-temperature environments performing high-intensity exercise are vulnerable to exertional heat stroke (21). An epidemiological survey of military personnel showed a steady increase in the morbidity and mortality of exertional heat stroke over the past decade (22), but effective recognition and prompt treatment can greatly reduce this rate (23). Therefore, it is necessary to strengthen military personnel's awareness of how to prevent and administer first-aid in the event of exertional heat stroke.

Strikingly, 85% of participants chose soda as a drink for heat victims, and 93.4% of participants believed that alcoholic beverages were beneficial for preventing heat-related illnesses during field training. This misinformation that alcoholic beverages and soda contribute to the prevention and treatment of heat-related illnesses might be related to media consumption. Military personnel may access information via television, the Internet, and smart phones (24), but information from these media usually has a commercial purpose, which can mislead the audience. For example, advertisements often link ice-cold beer

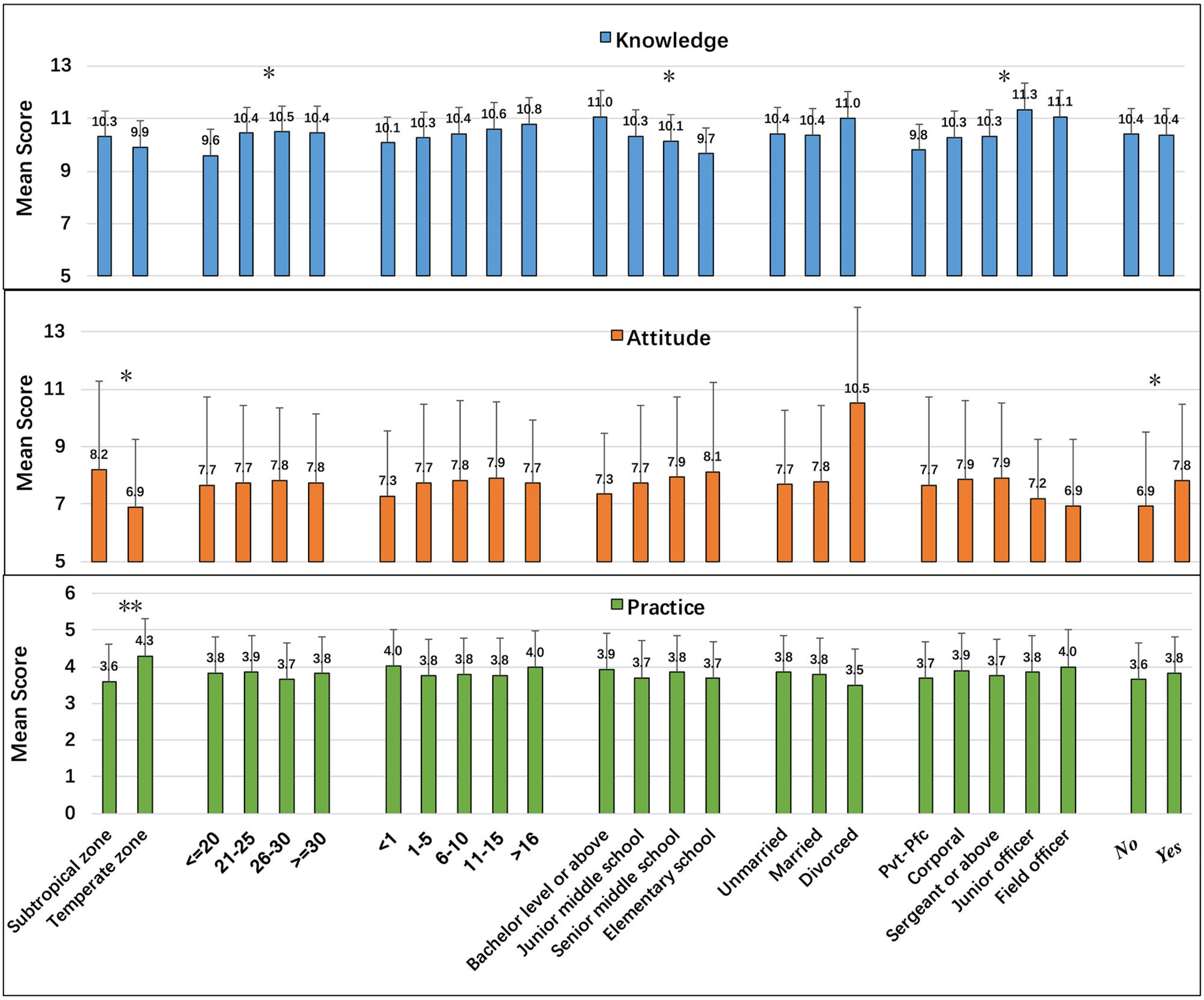

FIGURE 2 | Mean KAP scores according to demographic characteristics. *$P < 0.05$, **$P < 0.001$.

TABLE 4 | Correlations between knowledge, attitude, and practice scores.

Variable	Knowledge score	Attitude score	Practice score
Knowledge score	1		
Attitude score	0.004	1	
Practice score	0.020	0.170**	1

***P < 0.001.*

to hot summer weather and depict sportsmen in high-ambient temperatures delightedly drinking ice-cold soda. This erroneous information may be fatal at the critical moment for rescuing severe exertional heat stroke patients. According to a report in the New England Journal of Medicine, alcohol heightens the metabolic response to physical activity and is therefore a risk factor for exertional heat stroke. Thus, military administrators should strive to develop educational programmes in order to improve military personnel's knowledge about heat-related illnesses; moreover, governments should disseminate relevant knowledge on mass media.

By analyzing demographic characteristics, we found that participants who were younger than 20 years of age had lower K-scores than other participants ($P < 0.05$). This result was in contrast to the findings of Jing Li et al. (21). This might have been because participants in Jing Li's study had a large age range of 15–91 years, whereas the military personnel in our study were all young, with a mean age of 25.1 years. Additionally, K-scores were higher among junior officers ($P < 0.05$) with higher educational levels, which was similar to the results of previous studies (25). These findings suggest that we should provide health education on heat-related illnesses, especially to young military personnel. At the same time, since military officers have high educational levels and good mastery of relevant knowledge, administrators should take advantage of this, perhaps training these officers as instructors in health education projects.

The majority of respondents had good awareness of heat-related illnesses. Additionally, 87.5% of participants intended to take preventive measures at high ambient temperatures, and 75.1% of participants considered themselves sensitive to heat. Moreover, participants from the humid tropical zone had higher mean A-scores than those from the temperate zone. Conversely, when it came to the risks of heat-related illnesses, most participants (44.5%) reported little concern, possibly due to insufficient knowledge of these risks (26). Therefore, it is very important to enrich systematic educational resources with information about the risks of heat-related illnesses.

Pearson's correlation coefficient indicated a weak correlation between the A- and P-scores. This was consistent with the results of previous studies (27), whose authors reported that risk awareness is positively correlated with adaptation practices. An explanation for this correlation could lie in the health belief model, which asserts that health-related practices are determined by whether people recognize the seriousness of the problem and perceive themselves to be susceptible to particular illnesses (28). Therefore, good awareness of heat-related illnesses and the perception that there are benefits to taking action and fostering self-sufficiency against such illnesses promote preventive practices, which in turn reduce the adverse effects of heat waves. However, one subgroup in this study showed an interesting result: military personnel in the tropical zone had good awareness but low P-scores. This finding might be explained in part by three factors. First, people at low latitudes become better adapted to heat through behavioral and structural adjustment than people at high latitudes; this is called thermal acclimatization (29). Therefore, despite their positive attitudes toward heat-related illnesses, military personnel in the tropical zone performed limited protective behaviors. Second, the majority of participants were young men, who tend to be more willing than other people to take risks and to believe they can handle heat. Third, motivation and pressure from peers and instructors are likely to drive youths to perform beyond their physiological capability, which is also one of the major risk factors for exertional heat stroke (30). In summary, many factors might influence people's behavior, so further studies are needed to explore how to best promote and reinforce protective behaviors.

LIMITATIONS

There were several limitations in our research. First, our present study investigated only KAP of heat-related illnesses in Chinese naval officers and sailors; thus, caution should be used when generalizing the results to other military forces. Second, this study adopted convenience sampling, which could limit the representativeness of the results. Third, the questions in the questionnaires relating to KAP of heat-related illnesses were limited rather than comprehensive and sufficiently detailed, meaning that we might not have explored the relevant knowledge mastery, behaviors, and attitudes in depth. Fourth, in the designed questionnaire, the answer options varied among questions. Specifically, there were three- and four-point Likert scales, which may have biased the research results. Finally but importantly, the sampling error was enlarged due to the difference in sample size between the two subgroups.

CONCLUSION

Our research revealed that participants scored highly on most common-sense questions and demonstrated good awareness of and protective practices against heat-related illness. However, awareness of exertional heat stroke risks was inadequate. In addition, some differences, and personal experience. Thus, military personnel's awareness of preventive and first-aid measures against heat-related illnesses needs to be strengthened. To address these issues, it is very important to develop educational programmes and enrich systematic educational resources addressing heat-related illnesses.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the study was approved by the ethics committee of the institutional review board of the Naval Medical University. Written informed consent was obtained from all participants before the survey. All the data obtained was anonymous. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LG and SX conceived and designed the study and administrative support. XW undertook data analysis, results interpretation, and manuscript preparation. DX and XL organized the field works and collected the data. YW and KW was responsible for critical revision of the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.707264/full#supplementary-material

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Protocol for a Systematic Review on the Effectiveness of Interventions to Reduce Exposure to Occupational Solar UltraViolet Radiation (UVR) Among Outdoor Workers

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Background: Solar UltraViolet Radiation (UVR) is considered the most relevant occupational carcinogenic exposure in terms of the number of workers exposed (i.e., outdoor workers) and UVR-induced skin cancers are among the most frequent types of occupational cancers worldwide. This review aims to collect and evaluate all the available preventive interventions conducted on outdoor workers to reduce their solar UVR related risk, with the final purpose of reducing the burden of occupational skin cancers for outdoor workers.

Methods: We will search the following databases for peer-reviewed original research published: MEDLINE (through PubMed), Scopus, and EMBASE. We will include only interventional studies, both randomized and non-randomized, with an adequate comparison group, therefore excluding cross-sectional studies, as well as case-reports/series, reviews, and letters/comments. The systematic review will adhere to the "Preferred Reporting Items for Systematic reviews and Meta-Analyses" (PRISMA) guidelines for reporting systematic reviews. After the literature search, studies to be included will be independently reviewed by two Authors, first based on title and abstract, then based on the full text, according to the inclusion criteria. Conflicts will be solved by a third Author. Two authors will independently extract the required data from included studies and perform quality assessment according to the relevant domain for Risk of Bias assessment proposed by the Cochrane collaboration group. In case of sufficient homogeneity of interventions and outcomes evaluated, results from subgroups of studies will be pooled together in a meta-analysis.

Discussion: Following the principles for the evaluation of interventions for cancer prevention established by the International Agency for Research on Cancer, this systematic review will investigate the effectiveness of the interventions, and consequently it will provide reliable indications for the actual reduction of skin cancer incidence in outdoor workers.

Keywords: intervention, occupational exposure, outdoor worker, skin cancer, sun-safety, UltraViolet Radiation, workplace-based, systematic review protocol

INTRODUCTION

Occupational Solar Ultraviolet Exposure and Skin Cancers

Solar UltraViolet Radiation (UVR) is the most relevant occupational carcinogenic exposure in terms of the number of workers exposed (i.e., outdoor workers) (1–3) and it is the most important risk factor for the development of non-melanoma skin cancer (NMSC; also referred to as keratinocyte carcinoma—KC) (4) and malignant melanoma (MM) (5). The rising incidence of skin cancer over the years has made it a significant public health issue. In 2017, there were more than 3,00,000 cases of MM and about 7.7 million new cases of KC worldwide-—5.9 million due to basal cell (BCC) and 1.8 million due to squamous cell carcinoma (SCC) (6). The *International Agency for Research on Cancer* (IARC) legitimately classified UVR as carcinogenic to humans (Group 1) (7). Especially outdoor workers (e.g., construction workers, fishermen, and farmers) are exposed to high levels of UVR as they spend major parts of their working hours outside (8). Therefore, outdoor workers are at increased risk for developing (occupational) skin cancer. Epidemiologic data show the strikingly high occurrence of both BCC and SCC among outdoor workers after years of cumulative sunlight exposure and clearly demonstrate the relationship between occupational exposure to UVR and the incidence of KC (9–12). As anticipated, MM is also associated with UVR exposure, but especially intermittent solar radiation exposure, and in particular in early life, and accordingly the relation with occupational solar UVR exposure is considered less conclusive, even if some recent studies suggested a possible association of specific MM subtypes, such as lentigo maligna melanoma (LMM), with chronic lifetime sun damage (5, 13).

Current Status of the Management of the Occupational Solar UVR Risk

Millions of outdoor workers worldwide are exposed solar UVR during a major part of their working time. Despite this circumstance, this work-related risk factor is in many countries still not formally recognized by occupational safety and health (OSH) directives and regulations, and no specific occupational exposure limit values are officially available as a standard (14). A possible result of this inhomogeneous and scant recognition of the occupational risk is far from adequate implementation of fundamental preventive interventions for outdoor workers, as indicated by the large number of studies reporting high levels of individual UVR exposure at work (14, 15) and the inadequate adoption of sun-protective habits and behaviors by these workers (16). Among the negative consequences of this under-recognition of occupational risks associated with UV exposure, there is a lack of reporting of the cases, a lack of evidence on the effectiveness of health surveillance programs and screenings for the high-risk groups of OWs, a lack of compensation for cancer cases and a lack of political awareness to this increasing occupational health problem (13, 17, 18).

Collective and Individual Interventions for the Prevention of the Risk of UV-Induced Skin Cancers Among Outdoor Workers

Preventive interventions can be related to primary, secondary, and tertiary prevention. Primary prevention includes any preventive action aimed at reducing the incidence of cancer in humans (19). Considering the primary prevention of UV-induced skin cancers among outdoor workers, the strategies to be adopted can be on a collective and, if needed, also on an individual basis (20). First of all, it should be noted that primary prevention of occupational risks at the workplace could not be referred only to a company level, but it can be included in a wider approach, related to governmental and institutional preventive actions and policies, and the predisposition of specific norms, guidelines and preventive campaigns (18, 20). At the workplace, the first step of primary prevention includes the establishment of an adequate risk assessment process, to be reviewed and updated regularly. Based on the results of the risk evaluation, appropriate actions can be taken, including (but not limited to) technical measures as e.g., roofing of outdoor workplaces, use of panels and glasses to reduce solar UVR, and organizational measures as e.g., the organization of indoor work-breaks or, when not possible, breaks in shaded places, and the reduction of the exposure during the middle hours of the day (20).

Other important collective measures for the prevention of the occupational risk are the information of the workers, including e.g., the provision of informative materials like leaflets, signs or phone-messages, and the performance of specific educational training activities, including sun-safety trainings and skin cancers prevention trainings. These initiatives, and in particular those involving the educational training of the workers, can increase the knowledge and the appropriate perception of the occupational solar UVR risk, and they are considered fundamental for the prevention of skin cancers in outdoor workers (14, 16, 20).

On an individual basis, primary prevention of occupational risks consists of providing appropriate Personal Protective Equipment (PPE) to the workers. To reduce excessive solar UVR exposure, the individual protections available include: (1) sunglasses meeting adequate standards with appropriate solar UVR filtering large lenses, adhering to the face and large temples; (2) clothes made of UVR filtering fabrics, with long-sleeved shirts and trousers; (3) appropriate headgears as broad-brimmed helmets when required, or hats, possibly supplied with sun shields and a neck guard (19, 20). Moreover, other individual preventive protections are sunscreens, even if they cannot be considered PPE: appropriate sunscreens must filter both UV-A and UV-B rays, with a Sun Protection Factor (SPF) of at least 30, but better 50 or more, based on the photo-type and the UV-index. Sunscreens need to be water-resistant, easily applicable on the body and have to be frequently re-applied. To reach the protection level indicated by the SPF, the quantities to be applied are about 2 mg/cm^2 (20–22).

Secondary prevention includes the methods that can lead to the detection of precancerous conditions or cancers at an early stage (23). The two cornerstones of secondary prevention are screening and early diagnosis: in the workplaces, probably the most important measure of secondary prevention is the occupational health surveillance (HS) of the workers judged to be at increased risk of adverse effects, being exposed to relevant levels of solar UVR. HS aims at the prevention and the early diagnosis of UV-related adverse effects, with specific attention to subjects with conditions possibly determining a particular susceptibility to the risk (e.g., a fair skin photo-type). Moreover, HS usually includes periodic medical examinations of the workers from trained occupational health professionals, requiring, in case, supplementary health controls to be decided on an individual basis and the involvement of other medical specialists, such as dermatologists (13, 14, 18).

Finally, also tertiary prevention should be mentioned, even if it intervenes when the adverse effects are already manifested. Interventions in this field include the medical and occupational rehabilitation of the workers with UV-related skin cancers after the therapies and are aimed at ensuring a safe return to work, with full recovery from the disease and an adequate quality of life, as well as compensations for the occupational diseases diagnosed and properly notified to the authorities (18, 20).

Objective of the Systematic Review

The systematic review aims to fill a relevant gap in the scientific literature, evaluating the effectiveness of the available preventive interventions, as e.g., the ones listed in the previous sub-section, conducted in outdoor workplaces to reduce the solar UVR related risk of the exposed workers, with the final purpose of the prevention of UV-induced skin cancers among outdoor workers according to the definitions provided in the "IARC Handbooks of Cancer Prevention" (19, 23). A few other systematic reviews have been published on similar topics (16, 24–28), but none of these focused on interventional studies specifically in the broader context as defined by the framework outlined by the preambles of the IARC Handbooks of Cancer Prevention (19, 23).

METHODS

Protocol and Registration

The present protocol has been submitted to the International Prospective Register of Systematic Reviews (PROSPERO). The PROSPERO registration number is CRD42021251891. The current protocol follows the preferred reporting items for systematic reviews and meta-analysis protocols (PRISMA-P) (29) and subsequently the systematic review will be reported according to the respective preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement (30). In accordance with PRISMA-P this protocol provides the rationale for the systematic review, as well as the pre-planned methodological and analytic approach (29). The review process will start after the final definition of the protocol and all the phases are planned to be completed within the subsequent twelve-months.

Eligibility Criteria

We will consider eligible all the studies evaluating the effectiveness of interventions to reduce exposure to occupational solar UVR and the risk of skin cancers among outdoor workers. Our overall P.I.C.O. question is as follows:

Population = outdoor workers exposed to solar UVR targeted with preventive interventions aimed at reducing their skin cancer risk.

Intervention = preventive interventions, including primary and secondary prevention based on collective and individual measures addressed to outdoor workers, as:

a) Political and/or institutional initiatives, as the establishment of preventive actions to reduce the risk of UV-induced skin cancers among outdoor workers at a regional/national level.
b) Collective workplace interventions, including technical and organizational measures to reduce solar UVR exposure and the skin cancers risk.
c) Personal sun-safety information and training for the workers, including also specific campaigns aimed at raising awareness of the risk of skin cancers linked with solar UVR exposure, and of the importance of adopting adequate UVR protective behaviors, and of using appropriate personal protection.

Comparison = outdoor workers exposed to solar UVR for whom no preventive interventions aimed at reducing their skin cancer risk has been established.

Outcome = primary and secondary outcomes of the studies included in the systematic review are the following:

a) Primary outcome: effectiveness of the interventions in reducing the incidence of UV-induced skin cancers (SC) among outdoor workers, which are mainly KC, but considering also possible effects on malignant melanoma incidence in solar UV-exposed workers.

b) Secondary outcomes, considered as indirect measures of a reduced SC risk for outdoor workers: effectiveness of the interventions in implementing/improving/increasing the considered preventive measure(s)/protection(s), or reducing the incidence in case of adverse health effects, depending on the specific outcome as listed in the secondary outcomes.

Inclusion and Exclusion Criteria

Our target population is the working-age population, excluding child labor and unpaid domestic workers. We will consider outdoor workers (e.g., construction workers, farmers, gardeners, lifeguards, fishermen, and others) exposed to solar UVR in the workplace as the target population.

We will include studies of any publication year investigating the effects of different workplace sun-safety interventions and their effects on the reduction of occupational exposure to solar UVR and the incidence of skin cancers in exposed workers and on other secondary outcomes as listed below in the secondary outcomes. Studies written in any of the languages spoken by the Authors (i.e., English, French, Italian, German, Portuguese, and Spanish) will be included. Only human interventional studies with an adequate group for comparison (i.e., outdoor workers for whom the same interventions were not provided) will be considered. The types of study designs that will be included are interventional studies, both randomized and non-randomized, as well as observational studies, including case-control and cohort studies. Cross-sectional studies, as well as case-series studies and case-reports and publications without original data (e.g., reviews, letters to the editor, and editorials) will be excluded.

Types of Outcome Measures

The overall outcome of this systematic review is to assess the effectiveness of sun-safety interventions at work for the prevention of occupational skin cancers.

We refer to the definitions of "effectiveness" and interventions for primary and secondary prevention as reported respectively in the "IARC Handbooks of Cancer Prevention: preamble for primary interventions" (19) and in the "IARC Handbooks of Cancer Prevention: preamble for secondary interventions" (23).

Primary Outcome

The primary outcome of this systematic review is to assess the effectiveness of sun-safety interventions at work to reduce the incidence of occupational skin cancers, which are mainly KC, including basal cell carcinoma and squamous cell carcinoma, ICD-10 code C44, but considering also possible effects on cutaneous malignant melanoma incidence in solar UV-exposed workers, ICD-10 code C43.

Secondary Outcomes

The secondary outcomes considered are the following:

a) The reduction of the incidence of other solar UV-related skin diseases, e.g., sunburns, photo-aging, actinic keratosis, which are positively associated with an increased SC risk.
b) The improvement of the knowledge and of the risk perception of outdoor workers and employers concerning occupational solar UVR exposure and related health risks.
c) The improvement of the solar UVR exposure habits and protective behaviors of outdoor workers,
d) The implementation of new specific collective preventive interventions in the workplaces, including technical and/or organizational measures to reduce solar UVR exposure.
e) The improvement of the current preventive practices at a political/institutional level, e.g., the establishment of new preventive actions or campaigns aimed at reducing the SC risk for outdoor workers.

It should be noted that points (c), (d) and (e) represent both "interventions" possibly applied in specific studies, as well as secondary outcomes, to be evaluated after an appropriate follow-up, of an intervention aimed at reducing the SC risk for outdoor workers.

Information Sources and Search Strategy

The electronic databases searched for this systematic review will be PubMed MEDLINE, EMBASE, and Scopus.

The search strategy is being developed on PubMed MEDLINE by two co-authors and will then be revised and tested by the co-authors and a Medical Librarian Expert. We are designing the search strategy to specifically address the study's objectives, including detailed terms related to PICO criteria and aiming not to miss any important studies in the field. After validation of the search, we will translate it for EMBASE and Scopus.

We will search also gray literature for publicly available materials, including reports and databases from recognized international organizations active in the field of cancer prevention (e.g., World Health Organization, International Labour Office, etc.), government agencies, and institutions of national occupational insurance systems, such as INAIL (Italy) or DGUV (Germany).

Finally, we will also include a hand search of the reference lists of previous reviews (forward and backward citation tracking) and eligible articles. Scientific articles written in any of the languages spoken by the Authors will be included. There will be no restrictions on the publication period. The expected date of the last update of the literature search is 31st of December of 2021.

Study Records

Data Management

The citations retrieved from the three electronic databases will be downloaded as Research Information Systems (RIS) files and imported into a literature administration software (e.g., EndNote X9, Zotero, Mendeley, etc) and into the software used for facilitating the study selection process (e.g., Covidence, Rayyan, etc.), with automatic identification and exclusion of the duplicates upon importation.

Selection Process

The results of the literature searches will be imported into the identified software(s) for the initial screening, after the removal of the duplicates.

The selection of the potentially eligible studies will rigorously follow the pre-determined inclusion and exclusion criteria outlined above.

The first step of the selection process includes the screening of titles and abstracts, which will be performed independently by at least two reviewers, while third reviewers not having participated in this screening phase will solve any conflicts of inclusion.

After the initial screening, the full texts of potentially eligible studies will then be examined by at least two reviewers. Also, in this case, eventual conflicts will be solved by third reviewers not involved in the screening, while any other discrepancies at all stages of study selection will be resolved through discussion and consensus among the Authors' group. Results of the screening process will be presented in a PRISMA flow chart (29, 30).

Data Extraction Process

Each study will be double-reviewed and data will be independently extracted in pre-defined tables reporting all the relevant information (e.g., study ID, title, country, study setting, population, participant's characteristics, type of study, starting date, ending date, method of recruiting participants, the total number of participants, type of intervention, intervention goal, intervention assessment, outcome data, conflicts of interests). The data extraction forms will then be checked by a third Author for accuracy. Discrepancies between the data extractors will be discussed until reaching a consensus. A detailed data extraction sheet is being developed specifically for this study and will be piloted in a minimum of four studies.

Quality Assessment of Individual Studies

We will assess the risk of bias of all the individual studies included in the systematic review. The assessment will be independently performed by two Authors and possible conflicts solved by a third Author. We will base our assessment on published tools for the assessment of the risk of bias in the studies, considering the IARC Preambles, and in particular, the points presented in the sub-chapter "Study quality and informativeness" (19, 23).We will use the Cochrane collaboration group tools ROBINS-I and RoB2, respectively for non-randomized and randomized studies (31). The overall risk of bias of the individual studies will be rated as low, moderate, serious, critical or with no information for non-randomized studies using ROBINS-I while low, some concerns or high for randomized studies based on an evaluation with the RoB2 tool.

Data Synthesis

We will provide a qualitative narrative synthesis of the aggregated results of the included studies, supported by forest plots and categorized by type of preventive intervention(s) provided to the workers and type of primary and secondary outcomes measured to evaluate the effectiveness of the intervention(s). The results will be summarized in tables containing the year, country, population and participants (outdoor workers), type of intervention and outcome(s), and the main relevant results (e.g., incidence rates, relative risks, etc.), unadjusted and adjusted, in this case with the reporting of the considered confounders. A descriptive synthesis of the findings from the included studies, structured from the interventions and outcomes details, will be provided. We will also perform subgroup analysis, considering the specific categories of outdoor workers (e.g., construction workers, fishermen, farmers, etc.), their ethnic/cultural background if available and the geographic area where the studies have been conducted. Whenever enough data (>2 estimates) available, we will conduct meta-analyses separately for estimates of the effectiveness of the intervention on the specific outcome. When we will find two or more studies with eligible effectiveness of intervention estimate, two Authors will independently investigate the heterogeneity of the studies in terms of types of studies, participants (including country, sex, age, and industrial sector or occupation), risk factor exposure, intervention, comparator and outcomes. If we will judge two or more studies for the relevant combination of country, sex, and age groups, or a combination thereof, to be sufficiently homogenous to potentially be combined quantitatively using quantitative meta-analysis, then we will test the statistical heterogeneity of the studies using the I^2 statistic. When the studies will be found to be sufficiently homogenous statistically, we will pool the risk ratios of the studies in a quantitative meta-analysis, using the inverse variance method with a random-effects model to account for cross-study heterogeneity. If quantitative synthesis will not be feasible, then we will synthesize the study findings and identify the estimates taking into account the overall evidence by considering the informativeness of the studies and the results of the risk of bias assessment.

DISCUSSION

Solar UVR-induced occupational skin cancers are an extremely relevant issue for outdoor workers (14, 17, 18), and while some general evidence on a positive effect in limiting the occupational solar UVR exposure of these workers is available (16, 25, 26, 28), precise and valid data on the effectiveness of interventional studies for the reduction of the incidence of SC in solar UV exposed workers are still lacking. In particular, this systematic review will follow the principles defined by the IARC in its Handbooks of Cancer Prevention (19, 23). Accordingly, we will investigate the effectiveness of the interventions defined in the IARC preambles, and consequently, we will be able of providing reliable indications for the actual reduction of skin cancers incidence in outdoor workers.

Strength and Limitations

Considering methodological aspects, the systematic review aims to follow a rigorous method for all the steps of the process, including study selection, data extraction, quality assessment, and reporting of the results, following internationally recognized tools, like those of the PRISMA and Cochrane research groups (30, 31). The main strength of our review will be, as mentioned above, the full adherence with the statements expressed by the IARC for the definitions of the effectiveness of the interventions for cancers' prevention (19, 23).

Unfortunately, we expect a probably low number of studies directly evaluating the primary outcome defined in the present protocol, i.e., the effectiveness in reducing the incidence of occupational SC in outdoor workers, and therefore we may need to focus on secondary outcomes as indirect indications of the decrease in SC occurrence: this will be most likely the main limitation of our systematic review.

We also expect to have a relevant number of studies rated with a poor quality assessment, according to the fact that we expect a majority of non-randomized studies, in which it would be more difficult to evaluate the effectiveness of the interventions due to the presence of various biases.

Dissemination

The systematic review will be submitted for publication to an international peer-reviewed scientific journal. Systematic review's summaries will be further presented in the form of structure scientific communications and articles for journals and national or international conferences.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

KS, SJ, TL, AM, and FG: conceptualization. MS, TL, KS, CS, and MR: methodology. MS, TL, MR, CS, AM: software. TL, FG, KS, SJ: resources. AM, MS, CS, and MR: data curation and writing—original draft preparation. TL, KS, SJ, and FG: writing—review and editing and supervision. All authors have read and agreed to the published version of the manuscript.

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Criteria for Occupational Health Prevention for Solar UVR Exposed Outdoor Workers-Prevalence, Affected Parties, and Occupational Disease

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Non-melanoma skin cancer (NMSC) is the most common cancer in western countries. Legislative bodies and stakeholders like WHO and EU strongly promote protection against solar UVR, especially in workers. Occupational health prevention must be introduced as a strong instrument in workers protection also with regard to occupational disease issues. To date, criteria for both occupational health prevention and occupational disease are missing and the identification of risk groups has no metric basis. Here I report a criteria analysis based on the largest comprehensive data set of occupational ultraviolet radiation exposure of outdoor workers. With detailed research on occupation-specific dosimetric measurements of 45.000 measurement days in 176 occupations and sub-occupations, it is possible to map criteria for occupational health prevention specifically and to identify affected occupations. The number of employees affected can be elucidated worldwide. For the first time, a direct link to retrospective occupational disease criteria could be established. Of the 176 occupations and sub-occupations selected for this work, 153 (=87%) exceed the criterion for occupational health prevention and thus need special attention. This includes all occupations with annual exposures of more than 150 SED. Employment figures for the EU and the world yield the total number of affected workers to be 36.1 million and more than 500 million, respectively. These new criteria for occupational health prevention are valid and in good agreement with international research on limit values by WHO and ICNIRP. If applied correctly and consistently, these criteria can prevent occupational disease. It will be possible to identify occupations and sub-occupations that have an urgent need for prevention to avoid chronic skin damage leading to cancer. This research serves as a basis for policy making and clinical risk identification, as well as for daily practice of occupational physicians and employers responsible for risk assesment.

Keywords: UV radiation, occupational health prevention, occupational safety and health, UV personal dosimetry, occupational disease, skin cancer

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INTRODUCTION

Non-melanoma skin cancer (NMSC) is the most common cancer in western countries. NMSC includes squamous cell carcinomas (SCC), including actinic keratoses (AK) and basal cell carcinomas (BCC). For the same exposure situation, the extent to which the population is affected depends, in part, on the distribution of skin types according to the Fitzpatrick scale (1), which describes and classifies the tolerance of the skin to solar ultraviolet radiation (UVR). In addition to the benefits for dermatology, the classification according to the Fitzpatrick scale has been used directly in prevention, for example in workers protection evaluation criteria (2, 3).

The WHO attaches great importance to NMSC by UVR. It has been reported that 65–90% of all skin cancers are attributable to solar UVR exposure (4, 5), even by collaboration centers (CC) of the WHO like the Cancer Council Australia (www.cancer.org.au). NMSC occurs frequently, but death is unlikely. Nevertheless, it has a considerable impact on the quality of life. Incidence rates continue to rise worldwide for both SCC and BCC (6, 7). This is also evidenced by the DALYs (Disability adjusted life years) (8), especially with regard to NMSC. From 2000 to 2019, it almost doubled from 0.032 to 0.06% (of total DALYs). It can be assumed that the DALYs for NMSC are underestimated, as reporting by both those affected and authorities is weak.

The particular importance of the issue has clearly increased, especially at the European level. The Beating Cancer (BECA) Committee of Members of the European Parliament (MEPs) set up by the European Parliament is dealing with the content of Europe's Beating Cancer Plan (9). It was stipulated that the incidence of cancer should be reduced by 30%. The BECA committee has also determined that occupational skin cancer is the priority target of the activities.

The prevention of work-related health hazards and the preservation of employability are of great importance and a task for the society as a whole. Occupational health prevention (OHP) is an essential part of occupational health and safety measures. The aim of OHP is the prevention and early detection of work-related diseases. It is also intended to contribute to maintaining employability and the further development of occupational health and safety. In Germany, OHP is based on the Occupational Health and Safety Act (10) and the Ordinance on Occupational Health Prevention (11), which are derived from the European Occupational Health and Safety Framework Directive 89/391/EEC (12). Generally speaking, OHP aims at improvements in the protection of the health of all employees by using findings regarding the causes of occupational diseases as a basis for improvements in working conditions. Regarding UVR, the focus is on advising workers on exposure and the resulting hazards to their skin and eyes. If physical or clinical examinations are not necessary or are refused by the employee, OHP is limited to a counseling interview.

With regard to exposure to solar UVR during outdoor activities, there is potential for improvement both in the context of prevention, for example in OHP, and with regard to the reporting and compensation of occupational diseases in many countries in Europe and the entire world. Germany has enacted legislation for both which may serve as proposals for the international community (13, 14). OHP must be offered to every employee in Germany whose activities meet certain criteria. Regarding UVR exposure, these include assessing the exposure period of the months from April to September, and the daily period from 11 a.m. to 4 p.m. (CEST). If an employee has worked outdoors for more than 1 h on more than 50 days during this period, he or she must be offered OHP. Thus, a distinct definition of outdoor workers at risk from solar UVR has been established by the German Federal Ministry of Labor and Social Affairs. To my knowledge, this is the first country in the world to do so. This legislation is backed up by extensive measurements of the actual UV exposure of workers in Germany (15).

NMSC as a recognized occupational disease is not widespread either in Europe or in the world (16). The epidemiology required often suffers from the fact that cancer registries do not report these types of cancer, or the data sets are qualitatively questionable or incomplete. Many cases are also not reported, resulting in a significant underestimation of incidence (17). In Europe, it has therefore been proposed that cancer registries in particular take up this special focus on cancers that have an identifiable, preventable risk factor as their cause, such as occupational UVR exposures (18).

This also proves the need for increased efforts in prevention with regard to the overall incidence and prevalence of these cancers. In Germany, the incidence of invasive SCC and BCC are in men 184.1 and 143.0 in women per 100,000 persons, respectively (19); *in situ* forms of cutaneous SCC, such as actinic keratoses or Bowen's disease are not included in these numbers. In Italy there is also the possibility of recognizing UVR induced skin cancer as an occupational disease. There, however, the reports are clearly below the rate that one would expect due to the geographical location. In the Trentino region, for example, an incidence of 61.5 was calculated for BCC and 16.3 for SCC, each per 100,000 citizens (20). But even there, the incidences are constantly rising, and it must also be considered that the prevalence of NMSC is higher in the south of the country than in the north (21, 22).

In the new and upcoming ICD-11, a distinction is made between the different entities of NMSC, so that a statistically reliable recording is possible through appropriate coding (23).

Experience with the occupational disease in Germany since its introduction in 2015 has proven the high incidence of these diseases. So far—cumulatively from 2015 to 2019—∼44,000 occupational disease reports have been filed with ∼60% being recognized. It is inconceivable that this number should be lower in other countries, especially in more southern countries, because of the higher radiation levels. Radiation levels directly depend on the solar inclination angle. Thus, the radiation is highest at the equator and lessens with increasing latitudie. For example, the erythemal active UVR level in Germany is only about 26% compared to the equator (24).

The aim of this work is to show which occupations and sub-occupations are affected according to scientifically based current legal criteria for OHP, as this is unknown so far. There is a direct applicability for other nations from the underlying data and findings and the fact that Germany in particular is a country located in higher latitudes. These data coupled with employment figures and economic directories allows the estimation of the number of people affected and the associated expenditure for the industry. According to known criteria, in this paper it is examined if the criteria are good for protecting against severe skin damage leading to an occupational disease.

METHODS

Recording Radiation Exposure

With the GENESIS-UV (15) project (GENeration and Extraction System for Individual expoSure), personal dosimetric measurements of UVR during occupations since 2014 were performed. Each of the 1,000 test persons was equipped with a data logger dosimeter to conduct measurements every working day for seven months from April to October (see **Figure 1**). It was possible to collect information on more than 250 occupations and sub-occupations. Sub-occupations summarize concrete activities of employees that are too vaguely defined in the superordinate occupation [e.g., according to ISCO (25)]. For example, the occupation of gardeners subdivides into ornamental gardeners, cemetery gardeners, and several others. These data are currently being published. Activity profiles are assigned to each occupational context, which allow a precise identification of the individual activities. In addition to cumulative values and their statistical basis, individual daily doses of UV exposure can be presented for each occupation as well as for each test person. Furthermore, the measured values measured with GENESIS-UV every second can also be aggregated to half-hourly values. This plays a decisive role in the analysis of the criteria for OHP in this paper. An example of the structure of the available data is shown in **Figure 2**.

Since 2020, the exposure during leisure time activities is currently determined with GENESIS-UV. More than 500 test persons have been active over seven months so far. With the help of time use information for the population from the Federal Statistical Office, the average exposure of the population (or even individual groups) can be determined in detail and validated. Time use information describe the fraction of time which is spent for a distinct activity as a fraction of a 24-h-day. All activities for a group of people are included, e.g. such as sleeping, work, family time, sports, media use. This information is available down to a minute level. If such time use information is also known for other countries, then these results can be applied directly. At present, a surprisingly high average exposure of the population in Germany of 260 SED [SED, 1 SED = 100 J/m² erythema-effective irradiation; corresponds to about one half sunburn dose for skin type I on the Fitzpatrick scale (3)] per year is already emerging. This provisional value is used for modeling in this paper.

We have developed a new overall metric based on personal dosimetric measurements, which is currently being published (26, 27). With this, a holistic overall view of all exposures in connection with solar UV radiation is possible.

FIGURE 1 | Photograph of a test person at work. The dosimeter was worn by the subjects on the left upper arm as standard (Image/IFA).

Patient and Public Involvement

No patients were involved. The test persons were acquired with the support of German social accident insurance institutions, which are in close contact to enterprises of their branch. First of all, occupations were selected that were associated with a supposedly high UV exposure. In this field, the potential test persons were then directly approached and recruited based on their willingness to participate. The measurements, which took place exclusively during daily working hours in the period from April to October, were compensated with an expense allowance.

Criteria Analysis for Occupational Health Prevention

According to the legally anchored scientific opinion, OHP must be granted to every person who was active outdoors for more than 1 h between 11 a.m. and 4 p.m. (CEST) on more than 50 days in the period from April to September. If one calculates a quota from this, it is about 40% of the working days (20 working days in April, June, and September, or 21 working days in May, July, and August, respectively).

In Germany, exposure-risk relationships have been described for the risk-based concept in handling carcinogenic agents since 2005. Health-based occupational exposure limits often cannot be derived for carcinogenic agents because there is usually no exposure at which an adverse health effect on workers can be completely ruled out (28). The establishment of substance-specific exposure-risk relationships makes it possible to derive acceptance and tolerance concentrations associated with a defined, additional cancer risk. Thus, a risk is assigned to an exposure at the workplace (quantity/m^3) based on an 8-h working day. According to the German law, a risk of 4/1,000 new cancers is tolerated and must not be exceeded. This concept can also be transferred to the risks associated with physical agents. The attempt to quantify the risk of skin cancer resulting from UVR exposure serves to compare work-related risks and is based on the data currently available. To simplify matters, this calculation is based on a linear dose-response relationship,

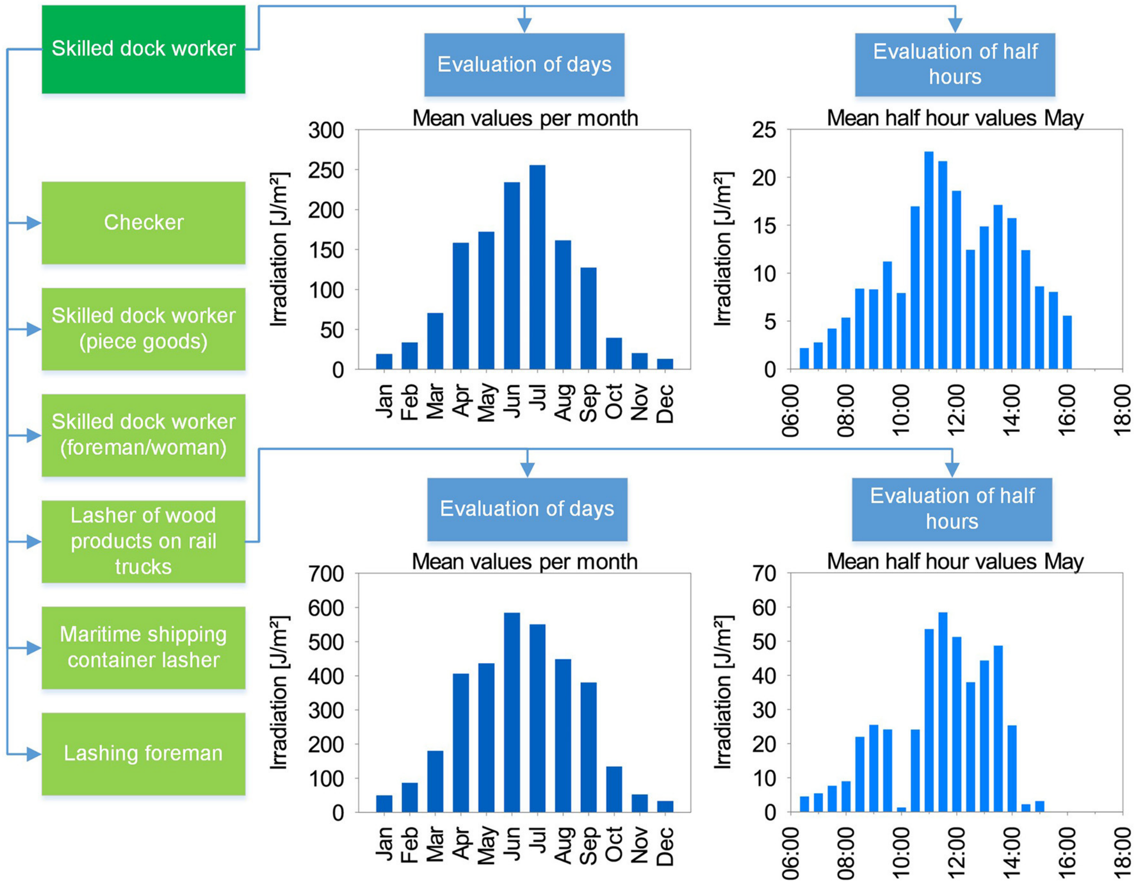

FIGURE 2 | Data structure in GENESIS-UV using the example of skilled dock workers. Several sub-occupations (light green) can be assigned to one occupation (dark green). Detailed data is available in each case, giving a monthly daily average, as well as the daily distribution in half-hourly values, each month-related (here: example from month May).

although the relationship between UVR and SCC could be described with an exponential function.

The incidence rate of SCC in Germany is in the range of 100/100,000 (=1/1,000), as described in the introduction. In order to estimate the tolerance risk, the legally binding scientific justification for skin cancer as occupational disease is taken as a basis. Considering the annual and daily cycle of the UVR exposure, only the period from April to September (northern hemisphere) and the time interval 10:00–15:00 o'clock, respectively, are relevant. This time period covers 88% of the annual and 75% of the daily UVR (24).

Calculations lead to the point that an exposure of 1 h in the period mentioned above is below the tolerance risk and thus fulfills the exposure-risk relationship (29). Longer exposure leads to higher risk and will exceed the tolerable risk level. This finally is the rationale to chose 1 h per day as criterion for OHP that must not be exceeded.

Conversely, this expert opinion also states that 1 h of UV exposure per day is tolerable, regardless of the occupation. The occupation/sub-occupation that shows the highest exposure in 1 h thus defines the tolerable upper limit. This can be a different occupation/sub-occupation in each month, since the exposure strongly depends on the individual activities. From our database, for each month, the occupation/sub-occupation with the highest UV exposure in 1 h is searched and set as the tolerable reference limit (see **Table 1A**). In the next step, for every occupation/sub-occupation the number of days per month where daily irradiation is above this reference limit is counted (example see **Table 1B**). The sum of these days from April to September is divided by the total number of measurement days in the respective occupation/sub-occupation. The result is a ratio that indicates the proportion of employment days in the occupation/sub-occupation that are above the limit. If this exceeds 40%, OHP is required according to the criterion defined above.

To carry out this analysis, a total of 45,000 measurement days were available across all occupations and sub-occupations.

The annual exposure values are available for all occupations and sub-occupations. If one defines that the occupation/sub-occupation with the highest annual exposure has been full-time exposed, then one can relate all other occupations to this and obtain information about the proportion of the occupation that takes place outdoors. In a diagram, this "quota" can be plotted

TABLE 1A | Occupation and sub-occupation with the hightest exposure in 1 h per month.

Month	Occupation	Sub-occupation	Timeslot [CEST]	Value [J/m^2]
April	Cable fitter or linesman	Electrical fitter (e.g., electronics technician for power plants)	13:00–13:30 14:00–14:30	88.78
May	Service fitter, wind farm technology	Rotor blade maintenance on wind turbines	12:30–13:00 13:30–14:00	98.21
June	Facade construction worker	Roof builder	11:30–12:00 13:30–14:00	109.31
July	Construction machine operator	Construction machine operator and canal/sewer/drain engineering worker	13:00–14:00	95.82
August	Overhead line worker/technician	Overhead line worker/technician	13:30–14:30	117.29
September	Elevation platform operator	Elevating platform operator	13:00–14:00	91.38

All other occupations show lower hourly exposures within the respective month.

TABLE 1B | Example for determination of quota for OHP.

	Days above level						Totals		
Occ./Sub-Occ.	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Sum**	**#MMD**	**Quota OHP [Ratio %]**
Bricklayer	83	110	112	130	74	100	609	782	78
Roofer	303	353	349	351	255	310	1,921	2,243	86
Kindergarten teacher	81	122	91	114	51	43	502	1,755	29

The number of days above the tolerable reference limit is counted for every occupation and sub-occupation. Next, the sum of these numbers is set into relation to the total number of measurement days in that respective occupation/sub-occupation (#MMD). The result is the quota OHP in %.

against the "quota" from the proportion of days above the limit for OHP described above. A diagram is obtained which describes how the exceeding of the precautionary criterion is related to the annual irradiation. From the carry-over at the position of the 40% criterion from the OHP, the corresponding annual exposure can be derived (see **Figure 3**).

If one knows which occupations/sub-occupations are included, it is possible to estimate the number of people affected due to the variety of occupations investigated in the GENESIS-UV projects. For this purpose, the number of employees from the classification of occupations of the German Federal Employment Agency is accounted if this occupation is above the criterion of 40%. This results in the total number of people affected in Germany. This can also be directly transferred to the European Community via the NACE Rev.2 database (30). Due to the imprecise information on occupational fields, only a rough estimate based on ILO data can be made for the entire world (31).

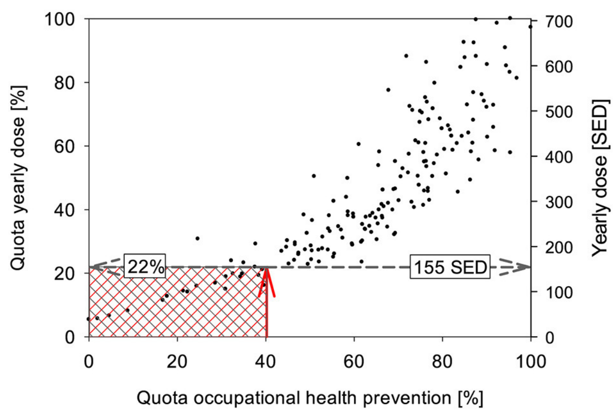

FIGURE 3 | Relationship between the rate of days exceeding criteria ("OHP quota") and the annual irradiation. The red arrow indicates the position of the criterion and its mapping to the distribution of the data, the gray arrow the mapping to the axes of the annual irradiation and its rate. Occupations/sub-occupations in the red shaded area do not meet the criteria for OHP, occupations/sub-occupations in the gray area are below the OD recognition criterion. The ranges are identical here, but may differ in case the criteria are defined differently.

Reference to Occupational Disease Incidence

So far, there is no direct link between the prospective effect of OHP and the retrospective view of occupational diseases. Since January 2015, legal regulations have been in force in Germany that allow recognition and compensation for SCC and AK, under certain conditions (13, 32).

To date, no fixed irradiation dose could be found that can be used as a threshold for the development of SCC. Apparently, there is a relative measure which depends on the irradiation during the year. The more UVR irradiation occurs, the higher the number of cases of SCC and AK (33).

In German legislation on occupational diseases, it has become a good standard to assess diseases without a concrete trigger threshold via the epidemiologically derived doubling of the risk of disease. Although the number of studies on this was relatively small, it was possible to find a relation. An increase of 1% UVR leads to 2.5% more cases of SCC (34). It was concluded that 40% more UVR leads to a doubling of risk (100%).

This defines the demarcation criterion between an occupational disease and the widespread disease: a superadditive dose-response relationship, given 40% extra occupational exposure of the "normal" lifetime exposure, can give rise to an additional 100% risk due to occupation. If this legal and epidemiological framework is fulfilled, then the disease is considered to be occupationally caused. Although this criterion is legally specific only to Germany and Denmark, it forms a reliable and comprehensible basis for overall. Each person is assigned an average annual irradiation of 260 SED, which, after multiplication by age at initial diagnosis, yields the so-called "normal" lifetime irradiation (24).

In a hypothetical but typical case of a 65-year-old employee with 45 years of occupational outdoor work, the "normal" lifetime exposure calculates to be 16.900 SED, and thus the extra occupational dose is 6.760 SED to double the risk. Assuming longtime involvement with rather the same activities throughout the years, it can be calculated what average annual occupational exposure this person would have had to acquire in order to eventually meet the recognition requirement. This is 150 SED per year.

Ideally, OHP prevents an employed person from having to suffer an occupational disease or an occupational illness. By comparing to a hypothetical case of occupational disease as a basis, it can be estimated for the first time if the legal criterion chosen is suitable to do so. So far, there has not been a sufficiently large database of a physical or chemical agent to be able to make such a comparison.

Criteria of precaution must be suitable to prevent a later disease. Therefore, the two threshold values from the criterion for OHP and OD, respectively, must be comparable, ideally the value from OHP is much smaller. Then it could be concluded that a criterion has been found which has the goal of sparing the employee the fate of an occupational skin cancer disease. In addition, the affected occupations/sub-occupations would be identified and recorded.

RESULTS

The vast majority of the occupations and sub-occupations investigated so far exceed the threshold for the provision of OHP (**Supplementary Table 1**). Occupations from all sectors of the economy can be found above the relevant 40%. It is interesting to note that some employees who are known to work more than 1 h outdoors do not meet the criterion according to this analysis, for example educators or parts of forestry workers. Conversely, however, employees who were not previously in the focus, such as professional drivers in freight transport, surveyors or warehouse and transport workers, come into consideration. Viewed in a different way, the resolution of the data gives an indication that the breakdown of occupations into sub-occupations is of great importance in determining occupational safety and health measures, including OHP. In this way, sub-occupations can be identified for which the provision of OHP is not necessary (example: tower crane operators in the group of construction machinery operators), or is necessary in contrast to the occupations (example: workshop workers in the occupation of agricultural machinery mechanics). Of the 176 occupations and sub-occupations selected for this work, 153 (=87%) are so strongly associated with exposure that special OHP must be implemented. From the context in **Figure 3** it follows that all occupations with an annual exposure of more than 155 SED require OHP.

Based on the federal German employment figures, the total number of affected persons can be extrapolated for Germany (see **Table 2**). According to this, about 7.2 million employees are eligible for OHP. If this is put in relation to the total number of employees of about 45 million, this makes up a share of about 16%. Up to now, a much smaller share had been assumed in Germany, namely about 5%. The transfer to the European level succeeds by assuming that employment in the economic sectors is on average similar to Germany. Therefore, for the 28 member states of the European Union (EU-28, 2019) with a total number of 225.7 million employed persons (quotation from Eurostat), one can estimate that about 36.1 million employees would be affected.

A further step is extrapolation to the global level, but this can only be an estimate. Significantly different distribution of economic sectors in the specific countries, different behavior, also with regard to exposure, informal work make the extrapolation imprecise. Assuming 3 billion employees worldwide (global workforce) and transferring the quota of those affected from the EU, this results in a number of 480 million employees. However, as occupational health and safety standards are lower in many countries and the number of employees in the agricultural, construction and raw materials extraction sectors is higher, a significantly higher number of people affected can be expected. A more detailed information can be elucidated from the ILO Legal Database on Industrial Relations (IRLex) [ILO, Geneva (www.ilo.org/irlex)] by comparing countries on legislation and else and the labor force statistics of the Organization for Economic Co-Operation and Development (OECD) worldwide (https://stats.oecd.org).

This is to compare to the average annual irradiation a person would have to acquire in order to be exposed to twice the risk of disease compared to the average population, as explained in detail in the Methods section. At the age of 65, a person living in the middle latitudes would receive an average lifetime irradiation of 16,900 SED, to which 6,760 SED would have to be added in order to double the risk. Equally distributed over 45 years of working life, this results in an average irradiation of 150 SED, which would have to be acquired at least annually.

DISCUSSION

Occupational health prevention for exposures to natural UVR is an important component in the prevention of UVR related

TABLE 2 | Number of employees affected in Germany by exceeding OHP criteria based on official German Federal Statistical employment data of the different sectors.

Industry sector in Germany	# Employees affected
Agriculture	400,979
Animal husbandry	33,798
Occupations in the horse industry	13,104
Occupations in the horse industry-horse breeding	500
Supervision and management—horse industry	463
Animal care	30,574
Viticulture	3,939
Forestry, hunting, landscape management	48,119
Horticulture	381,094
Mining, open-cast mining, blasting	23,244
Natural stone and mineral processing occupations	13,498
Woodworking and wood processing occupations	82,107
Production of wood-based materials and components	10,185
Occupations in wood, furniture, interior construction	154,087
Metal construction occupations	284,751
Supervision—metal construction and welding	10,238
Occupations in renewable energy technology	7,206
Occupations line installation, maintenance	20,755
Structural and civil engineering occupations	745,438
Screed and terrazzo laying occupations	4,765
Painters, plasterers, building sealers, building protection	187,849
Dry construction, iso-room-glass roll construction	187,092
Supply and disposal	207,904
Warehousing, postal services, delivery, cargo handling	2,706,416
Vehicle guidance in road traffic	1,500,570
Construction and transport equipment management1	114,600
Sports instructors	45,992
Sum	7,219,267

skin cancers. Ideally, OHP prevents an employed person from suffering an occupational illness or disease. Up to now, there has been a lack of metrological and scientific proof as to which occupations or sub-occupations are particularly highly exposed and what effects can be expected on the subsequent occurrence of illness. This work solves this problem and for the first time brings OHP and OD into a metric context.

No studies can be found in the international literature that are based on an equally large sample of subjects and data. Measurements of exposure have often been performed using a technique that does not allow for day- or even hour-resolved analyses (35–37); also, there is a lack of breadth in the choice of occupational activities (38–41). None of the studies have analyzed the measured values with regard to occupational health issues, but have aimed exclusively to determine irradiation (42–45). Grandahl et al. (46) recently also performed detailed time-resolved recordings of exposure.

With this new metric, it was possible for the first time to define criteria of OHP regarding UV exposure based on measured values. The list of occupations and sub-occupations can be used directly in practice worldwide. The usefulness of this list becomes particularly clear when analyzing the individual economic sectors. While it is clear, as expected, that the construction sector is heavily affected, other sectors (agriculture, services, etc.) also contribute to the total of at least half a billion people worldwide (EU: 36 million, Germany: 7.2 million) who must be provided with effective prevention. According to the concept presented in this paper, the definition of "outdoor worker" can also be adressed. An outdoor worker is anyone who spends more than 22% of their working time outdoors (cf. **Figure 3**). The term outdoor worker has already permeated legislation and other bodies, so a clean definition is of great importance.

This study has limitations. As the data set was recorded in Germany, the transferability to other countries in terms of latitude has to be considered. However, this again tightens the criteria significantly, as UV irradiation increases towards the equator. Especially occupations that are now at the limit of the criterion will tend to be above it at lower latitudes. Comparative measurements of this is planned in other studies. In addition, the counting of individual days above the criterion may be subject to statistical fluctuations. Therefore, only occupations that showed at least 50 valid measurement days were selected for this study. In principle, the results obtained are subject to the problems of personal dosimetry measurements, but this was counteracted with a large number of subjects and an extremely high number of data sets (3.8 billion) and validation methods.

In principle, previously unrecognized occupational profiles may still be missing, but this can be inferred by analogy and expertise from the occupations studied so far in most cases.

Although the criteria for OHP and OD are only legally valid in Germany so far, they are based on the international state of science and can therefore be adopted for all nations and used as a basis for a scientific analysis.

Crucial to the success of OHP or prevention in general is its acceptance by workers, but also the conviction of those who are responsible and have to bear any costs. Since photodamage cannot be reversed but requires constant, lifelong aftercare and therapy, consistent and preventive occupational health and safety is of great importance. A future reduction in the burden of disease is currently being researched in systematic reviews initiated by the WHO and ILO (47). The return on prevention is obvious when one considers that simple measures of OHP and technical occupational safety are already sufficient to prevent serious and permanent medical interventions. For example, installation of shading (also in urban planning), reduction of time spent directly in the sun or wearing of long-sleeved clothing are simple, but very effective measures to reduce exposure. Therefore, it is a clear cost-benefit calculation in favor of prevention for both society and employers who have to pay into social security systems or provide direct compensation.

A further classification of these study results can be made by comparison with the exposure limit value of 1 SED per day (2, 3) proposed by WHO and ICNIRP, taking into account the vulnerable skin type I (1). From the selected criterion for OHP, an acceptable irradiation of 0.65 SED per working day can be derived, if one assumes an equal distribution of exposure over 230 working days per year. If the irradiation from leisure activities is also taken into account, this total irradiation is within the range of the proposed exposure limit value.

This work puts OHP for UVR exposure in a more concrete light. The high urgency for an enormously large number of people affected could be shown and leads to the realization that efforts in prevention must be significantly intensified worldwide. For the first time, it was possible to show a direct proof and connection between the criteria of OHP and possible future diseases. On the basis of this work, risk groups can be clearly identified, and given specific preventive care.

Special attention should be paid to the fact that occupational physicians, for example must be involved at an early stage. Medical doctors are already held in high esteem by people by virtue of their training, so that the content to be conveyed may have a better effect.

The insights gained in this work can be taken up by national and international organizations, interest groups and also legislators, as they allow direct implementation in regulations. Training curricula for the instruction of employees can be developed or updated according to the findings, in order to implement the aspirations of the WHO, the ILO and the EU outlined in the introduction. Consistency with the other measures of technical and behavioral preventive occupational health and safety, also and especially taking into account private exposures, would be an ideal, equally holistic approach to the prevention of skin cancer.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MW acted as sole author and performed the scientific analysis of the data.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.772290/full#supplementary-material

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Stimulating Sunscreen Use Among Outdoor Construction Workers: A Pilot Study

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Background: Outdoor workers (OW) receive a higher dose of ultraviolet radiation (UVR) compared to indoor workers (IW) which increases the risk of non-melanoma skin cancer (NMSC). Regular sunscreen use reduces the NMSC risk, however, adequate sun-safety behavior among OW is poor. The main objective was to conduct method- and intervention-related elements of a future intervention trial among OW, based on providing sunscreen and assessing sunscreen use on group- and individual level.

Methods: This pilot study was conducted at a construction site in the Netherlands from May-August 2021. Nine dispensers with sunscreen (SPF 50+) were installed at the worksite. OW ($n = 67$) were invited to complete two (cross-sectional) questionnaires on sun-safety behavior, before and after providing sunscreen. Stratum corneum (SC) samples for the assessment of UV-biomarkers were collected from the forehead and behind the ear from 15 OW and 15 IW. The feasibility of the following elements was investigated: recruitment, (loss to) follow-up, outcome measures, data collection, and acceptability of the intervention.

Results: The first questionnaire was completed by 27 OW, the second by 17 OW. More than 75 percent of the OW were aware of the risks of sun exposure, and 63% ($n = 17$) found sunscreen use during worktime important. The proportion of OW never applying sunscreen in the past month was 44.4% ($n = 12$) before, and 35.3% ($n = 6$) after providing sunscreen. A majority of OW (59.3%, $n = 16$) found sunscreen provision encouraging for sunscreen use, the dispensers easy to use (64.7%, $n = 17$) and placed in practical spots (58.8%, $n = 18$). Collecting SC-samples was fast and easy, and several UV-biomarkers showed higher levels for sun-exposed compared to less exposed body parts. There was no significant difference in UV-biomarker levels between OW and IW.

Conclusions: This pilot study revealed low sunscreen use among OW despite providing sunscreen, overall satisfaction with the sunscreen, and the sufficient awareness of the risks of UVR-exposure. Collecting SC-samples at the workplace is feasible and several UV-biomarkers showed to be promising in assessing UVR-exposure. The low participation rate and high loss to follow-up poses a challenge for future intervention studies.

Keywords: outdoor workers, solar radiation, non-melanoma skin cancer, sunscreen use, occupational disease, ultraviolet exposure, stratum corneum, biomarkers

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INTRODUCTION

Non-melanoma skin cancer (NMSC) incidence is rising in outdoor workers (OW) (1). The main cause of NMSC is exposure to solar ultraviolet radiation (UVR) and occupational exposure contributes to the overall lifetime UV dose (2, 3). The high and increasing incidence rates of NMSC—including frequent recurrence—have a considerable impact on the quality of life of the affected workers, and pose a significant burden for the health care system (4). The association between occupational UVR exposure and NMSC prevalence is recognized by the World Health Organization (WHO) and the International Labour Organization (ILO) (5, 6), and in six EU countries NMSC is also listed as an occupational disease (7).

NMSC can be avoided, if adequate measures to reduce UVR exposure are taken. There are several possible prevention strategies, including sunscreen use (8). Sunscreen is shown to be an effective strategy to reduce UVR exposure and its health consequences (9, 10). It is reported as a feasible measure to adopt by OW (11–13), and with regular use, sunscreens are able to prevent the formation of skin (pre)malignancies (9, 10). However, previous research revealed several barriers for OW to use sunscreen. These include the common belief that people with a tanned or dark skin are not at risk for skin cancer and protective measures are not necessary (9, 14), or that applying sunscreen is seen as a disturbance and a nuisance (9, 15, 16). Many OW are male and some feel it is not masculine to protect themselves from the sun (9, 17, 18). Adequate sun-safety behavior among outdoor workers is still poor (9, 19, 20), with examples of OW never using sunscreen and reporting sunburns during worktime (9). An important barrier for not using sunscreen is the cost of sunscreen (15), while providing free sunscreen has been reported as an effective intervention for promoting sunscreen use (21).

Apart from which prevention strategy is used, assessing the effect of such strategies in occupational circumstances is a challenge (21). Stratum corneum (SC) biomarkers showed to be promising markers to assess the internal UVR dose and immune response in experimental settings (22, 23). These are including *cis*-urocanic acid (cUCA), which is a sensitive, non-invasive marker of the internal UVB dose. However, its feasibility for assessing the UV-dose after chronic UVR exposure has not been investigated yet. The use of immunological SC markers—although less sensitive than cUCA—showed good possibilities to be suitable for detecting response at higher and/or repetitive UVR exposure.

We set up an intervention study focused on stimulating sunscreen use among outdoor construction workers, described in our previously published protocol (24). Unfortunately, due to the COVID-19 pandemic and the restrictive measures that were introduced, we were not able to perform the planned intervention study. Instead, we conducted a pilot study in which parts of the intervention study were carried out on a smaller scale (25, 26). For this pilot study, we followed the elements of study design reported by Blatch-Jones et al. (27) and adapted from Arain et al. (28). Elements investigated in this study were: recruitment, (loss to) follow-up, outcome measures, data collection, and the acceptability of the intervention. The main objective of this pilot study was to investigate the feasibility of these method- and intervention-related elements of the future intervention trial based on providing sunscreen and assessing sunscreen use on group level (monitoring usage) and individual level (SC biomarkers of UVR). We addressed the following research questions: what is the acceptability and feasibility of an intervention focused on providing sunscreen at the workplace? And what is the feasibility of collecting SC biomarkers of UVR exposure at the workplace?

MATERIALS AND METHODS

Design and Setting

We conducted a pilot study in which we investigated the acceptability and feasibility of an intervention focused on providing sunscreen at the workplace (part 1). Secondly, we assessed the feasibility of collecting SC biomarkers of UVR exposure at the workplace (part 2). The duration of the study was 16 weeks (May-August 2021), and the setting was a construction site in a northern province of the Netherlands. Measurements consisted of two (cross-sectional) questionnaires, interviews with managers (part 1), and biochemical analyses of SC biomarkers of UVR exposure (part 2). The study protocol followed the principles of the Declaration of Helsinki (2013) and was approved by the Medical Ethics Committee of the Academic Medical Center, Amsterdam, the Netherlands.

Participants and Recruitment

Part 1: Sunscreen Use

Participants were construction workers, engaged in outdoor work activities, and aged ≥18 years. The construction company (main contractor) was selected by the researchers because they offered frequent outdoor work tasks and therefore had a potentially high number of eligible participants. The eligible construction workers worked for several subcontractors hired by the main contractor. Work tasks consisted of scaffolding, fiber installation, paving, crane operation, and other construction work. The construction workers were recruited at the construction site by the researchers, and were informed on the study protocol in both oral and written form. Construction workers fulfilling the inclusion criteria were enrolled in the study and written informed consent was obtained.

Part 2: UV-Biomarkers

Fifteen indoor workers (IW) and fifteen OW were recruited at the construction site by the researchers. Participants either had a work task indoors (office workers) or a work task outdoors (construction workers). Participants were included on a first come, first serve basis, and inclusion was independent from their participation in the other part of this study. All participants had Fitzpatrick skin type 1, 2, 3 or 4 (29). Written informed consent was obtained.

Study Procedures

A Gantt chart of the study procedures is presented in **Figure 1**.

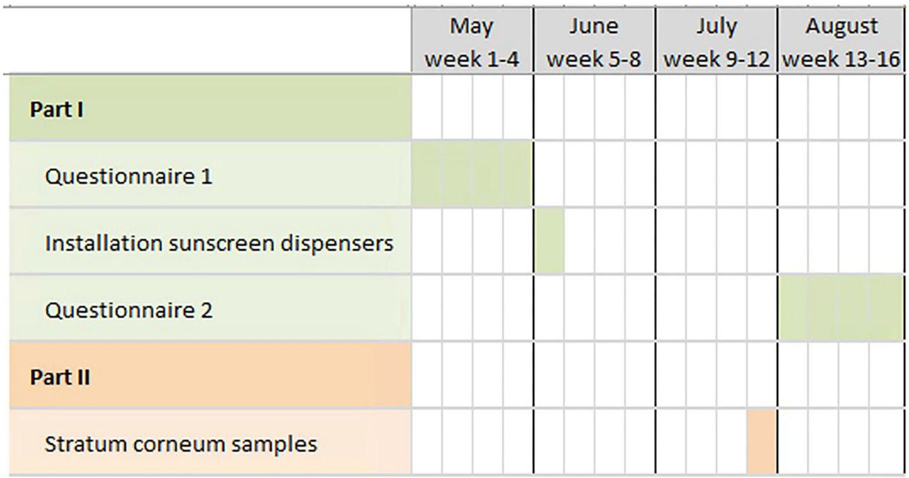

FIGURE 1 | Gantt chart of the study procedures.

Part 1: Sunscreen Use

Questionnaires

The participants were asked to complete the first questionnaire at the start (T = 0; before the installation of the sunscreen dispensers), and the second questionnaire at the end of the study (T = 16 weeks; 2 months after installation of the sunscreen dispensers), this were cross-sectional and self-reported measurements. The questionnaire included socio-demographic questions about age, sex, and country of origin. Skin type was defined using the Fitzpatrick skin types (29). Work characteristics included work status as outdoor worker, job characteristics (e.g., job task), and number of years in current profession. Furthermore, there were questions about sun-related risk knowledge (e.g., "sun exposure is primary cause of skin cancer" or "must apply sunscreen even when it is overcast"), attitudes (e.g., "when the sun shines I spend as much time as possible outdoors" or "sunscreen use at work is important to me"), barriers for using sunscreen (e.g., "sunscreen use is easily fitted into my working day"), outside leisure-time spending (e.g., "I spend >3 hrs outside on my days off"), and UV-protective behaviors (e.g., use of sunscreen ever or in the previous month). In the second questionnaire (T = 16 weeks) an additional question about the number of sunburn episodes during the past 3 months was included, as well as questions about satisfaction with the provided sunscreen. Questions were assessed on a five-point Likert scale, or as correct/incorrect and yes/no answer options. The questionnaires are presented in **Appendix I**.

The questions in the questionnaires were based on a standardized set for measuring sun protection behavior in OW (30). A pilot version of the questionnaires was tested on four OW (not included in this study). Based on their feedback, some alterations were made to the questionnaires (i.e., better clarification of Fitzpatrick skin type). The questionnaires were available in seven languages (Bulgarian, Dutch, English, German, Hungarian, Polish, and Romanian) and were translated by a professional translation agency. The questionnaires were available on paper (for the non-technology oriented participants) and online. The online questionnaires could be completed using a smartphone or computer. LimeSurvey (Hamburg, Germany) was used as survey tool.

Sunscreen Dispensers

At the construction site, nine sunscreen dispensers were installed at readily accessible strategic places (e.g., the canteen, changing rooms, entrance etc.), 4 weeks after the first questionnaire was completed. Next to the dispensers, an informative poster was placed advising the OW to "apply sun cream", presented in **Appendix II**. The dispensers were filled with sunscreen Stokoderm® Sun Protect 50 PURE SPF 50 UV skin protection lotion for professional use. This product is a cosmetic product regulated by and complying with Regulation EC no. 1223/2009 (as amended) on Cosmetics Products. The main UV-protection ingredients are ethylhexyl salicylate, bis-ethylhexyloxyphenol methoxyphenyl triazine, butyl methoxydibenzoylmethane, octocrylene, and homosalate.

Initially, we planned to use electronic dispensers equipped with a Wi-Fi transmitter recording each application event. However, technical difficulties prohibited us to electronically register sunscreen applications. Instead, at the end of the study, we removed the cartridges from the dispensers and weighed them using an analytical balance in order to investigate in which location a dispenser was used most or least.

Interviews With Managers Regarding the Sunscreen Dispensers

At the end of the study, three managers working for the main contractor were interviewed individually regarding their experience with the sunscreen dispensers. This was done following predefined questions such as "What did you think of the sunscreen dispensers?", "Where the dispensers located in practical places?" "Do you think this is a sufficient method to

TABLE 1 | Background characteristics of outdoor workers.

	Questionnaire 1 (T = 0 weeks) *n* = 27	Questionnaire 2 (T = 16 weeks) *n* = 17
Age (years ± SD)	34 ± 9.7	36 ± 8.8
Sex (males, *n*, %)	25 (93%)	15 (88%)
Smoking (*n*, %)		
Never	8 (29%)	4 (24%)
Quit	2 (7%)	2 (12%)
Yes	17 (63%)	11 (65%)
packs/day		
0.25	1 (4%)	
0.5	6 (22%)	4 (24%)
1	9 (33%)	7 (41%)
2	1 (4%)	
Skin type (*n*, %)		
I	2 (7%)	1 (6%)
II	2 (7%)	5 (29%)
III	19 (70%)	8 (47%)
IV	4 (15%)	3 (18%)
Country of birth (*n*, %)		
Belgium	1 (4%)	
Bosnia and Herzegovina	3 (11%)	
Brazil	1 (4%)	
Bulgaria	3 (11%)	2 (12%)
Croatia	1 (4%)	1 (6%)
Hungary	1 (4%)	
Ireland	5 (19%)	2 (12%)
Lithuania	1 (4%)	1 (6%)
Poland	3 (11%)	
Romania	3 (11%)	5 (30%)
Spain	1 (4%)	
The Netherlands	1 (4%)	4 (24%)
United Kingdom	3 (11%)	2 (12%)
Job as construction worker		
0–1 year	5 (19%)	2 (12%)
2–5 years	9 (33%)	5 (29%)
6–10 years	7 (26%)	1 (6%)
11–20 years	2 (7%)	5 (30%)
>20 years	4 (24%)	3 (18%)
Outdoor on workday (*n*, %)		
0–1 h	5 (19%)	1 (6%)
2–4 h	7 (26%)	5 (29%)
>4 h	15 (56%)	11 (65%)
Work task outdoor		
Scaffolding fitter	5 (19%)	1 (6%)
Fiber installation	8 (30%)	2 12%)
Paving	2 (7%)	3 (18%)
Crane operator	2 (7%)	
Other	10 (37%)	11 (65%)

protect OW against the sun?" "Do you have tips to make this work better?". The questions were asked as open questions, and more details were asked if needed. Each manager was interviewed for about 10 min.

Part 2: UV-Biomarkers

Stratum Corneum Biomarkers of UVR Exposure

SC samples were collected at T = 12 weeks. The SC was collected using adhesive tape strips, a minimally invasive, non-painful method which is extensively used in experimental studies (22, 31, 32). Adhesive tape discs (1.54 cm^2, D-Squame; CuDerm, Dallas, TX, USA) were attached to the skin. Each tape was pressed on the skin for 5 s, using the thumb. The tape strips were removed gently with tweezers and stored in a closed vial at −80°C until analysis. SC samples (six tapes per sample location) were taken from skin sites exposed to the sun (i.e., the forehead) and a less exposed skin site (i.e., behind the ear).

Sample Analysis

Based on our previous studies (22, 23), the investigated markers of UVR exposure included *cis*- and *trans*-isomers of urocanic acid (UCA), and fifteen immunological markers: IL-18, IL-8, IL-33, IL-10, IL-1β, IL-1α, IL-1RA, MMP-9, VEGF, GM-CSF, MCP-4, MIP-1β, MIP-3α, CCL27, and CCL17.

Determination of UCA Isomers

The 3rd tape was used to determine *trans*-UCA (tUCA) and *cis*-UCA (cUCA). UCA isomers on the 3rd tape were extracted with 600 μl of Millipore water and subsequently analyzed by high-performance liquid chromatography (HPLC-UV), according to the method described in detail elsewhere (22, 33). The limit of detection is 0.14 $\mu mol\ L^{-1}$, and the lower limit of quantitation is 0.45 $\mu mol\ L^{-1}$.

Analysis of Immunological Markers

Extraction of immunological markers and soluble proteins from the 4th and 5th tape was performed as described before (22). In short, 1.2 mL phosphate-buffered saline (Merck, Darmstadt, Germany) with 0.005% Tween 20 (Sigma-Aldrich, Zwijndrecht, the Netherlands) was added to the cryo-vial containing the 4th tape. An ultrasound bath (Branson 5800, the Netherlands) was used for extracting immunological markers and soluble proteins. The extract from the 4th tape was transferred to the cryo-vial containing the 5th tape, repeating the procedure. Extract aliquots of 300 μL were distributed in micronic-vials and stored at −80°C until further analysis.

Concentrations of the fifteen immunological markers were determined using MESO QuickPlex SQ 120 (MSD, Rockville, MA, USA) according to the manufacturer's instructions. To correct for the variable amount of SC on each tape, the concentration of immunological markers was normalized by protein content, which was determined using Pierce Micro BCA Protein Assay Kit (Thermo Fischer Scientific, Rockford, IL, USA).

TABLE 2 | Sunscreen use behavior.

Question	Answers	Questionnaire 1 (T = 0 weeks) *n* = 27	Questionnaire 2 (T = 16 weeks) *n* = 17
Sunscreen use	Never considered using	5 (19%)	3 (18%)
	Considered it, not decided	5 (19%)	4 (24%)
	Not using	3 (11%)	–
	Will use	2 (7%)	4 (24%)
	Already using	11 (41%)	6 (35%)
Sunscreen application past month	Never	12 (44%)	6 (35%)
	Rarely	4 (15%	2 (12%)
	Sometimes	8 (30%)	7 (41%)
	Often	1 (4%)	2 (12%)
	Always	1 (4%)	–
Sunscreen applications per day	0	9 (33%)	6 (35%)
	1	12 (44%)	7 (41%)
	2	4 (15%)	2 (12%)
	3	1 (4%)	1 (6%)
	≥4		1 (6%)
Sunscreen application times (multiple answers possible)	Morning before work	15 (56%)	8 (47%)
	Coffee break	4 (15%)	7 (41%)
	Lunch	8 (30%)	7 (41%)
Encouraging sunscreen use (only "yes")	Provided by employer	16 (59%)	9 (53%)
	Employer regularly emphasizes its importance	13 (48%)	8 (47%)
	Colleague also use sunscreen	14 (52%)	6 (35%)
	Protecting against skin cancer	23 (85%)	12 (71%)
Not considering sunscreen use necessary because: (only"yes")	When the sun shines I work in the shade	12 (44%)	8 (47%)
	I use protective clothing	16 (59%)	10 (59%)
	I like tan skin	13 (48%)	8 (47%)

TABLE 3 | Knowledge of sun risks and behavior in the sun.

Question	Answers	Questionnaire 1 (T = 0 weeks) *n* = 27	Questionnaire 2 (T = 16 weeks) *n* = 17
Must apply sunscreen even when it is overcast	Correct	15 (56%)	13 (77%)
	Incorrect	12 (44%)	4 (24%)
Sun exposure is the primary cause of skin cancer	Correct	22 (82%)	17 (100%)
	Incorrect	5 (19%)	
If I have tan skin I no longer need to apply sunscreen	Correct	1 (4%)	2 (12%)
	Incorrect	26 (96%)	15 (88%)
When the sun shines: (only "yes")	I spend as much time as possible outdoors	14 (52%)	9 (53%)
	I always use sun protection	15 (56%)	9 (53%)
	I seek shelter in the shade or stay indoors	15 (56%)	8 (47%)
	I spend >3 h outdoors on my days off work	17 (63%)	12 (71%)
Sunscreen use at work (only "yes")	Is important to me	17 (63%)	11 (65%)
	Is easily fitted into my working day	18 (67%)	14 (82%)
	Is something I do before I start working outdoors	16 (59%)	8 (47%)

Statistical Analysis

Part 1: Sunscreen Use

Data analyses for the questionnaires were performed with IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp. Armonk, NY, USA). Answers were assessed on five-point Likert scales (disagree wholeheartedly, disagree, do not agree/do not disagree, agree, agree wholeheartedly; or never, rarely, sometimes, often, always), or correct/incorrect and yes/no answer options. Data analyses included counts with percentages and other descriptive statistics (median, IQR).

Part 2: UV-Biomarkers

Data analyses for the SC samples were performed with GraphPad Prism 8 software (GraphPad Software, San Diego, CA, USA). Data distribution was assessed with the Shapiro-Wilk normality test. Mann-Whitney *U* and Wilcoxon ranking tests were used for comparing the levels of immunological markers and cUCA between and within both groups (i.e., OW and IW), respectively. The relative amount of cUCA (*cis*-UCA/(*cis*-UCA+*trans*-UCA)) represents the proportion of initially present tUCA that is transformed to cUCA. Two-sided *p*-values of <0.05 were considered to be statistically significant. Data are presented as median with interquartile range (IQR) when non-normally distributed, or as mean values ± standard error of the mean (SEM) when distributed normally.

RESULTS

Part 1: Sunscreen Use

After recruitment, 67 outdoor construction workers were eligible for inclusion in this study and were invited to complete the questionnaires. The first questionnaire was completed by 27 participants (loss to follow-up 60%) and the second one by 17 participants (loss to follow-up 75%). Background characteristics are presented in **Table 1**. Median age (IQR) of the participants was 33 years (22, 24–41)—first questionnaire—and 35 years (22, 29–42)—second questionnaire—. They mostly had skin type III, and a majority of the participants were male and smokers. Approximately 20% of the participants worked in construction for over 20 years, and the majority worked outside for >4 h per day.

Sunscreen Use Behavior

Table 2 shows the results of sunscreen use behavior of the participants. Before installation of the sunscreen dispensers, 19% ($n = 5$) of the OW never considered using sunscreen, this percentage was 18% ($n = 3$) after the dispenser installation. At baseline, 30% ($n = 8$) of the OW "sometimes" applied sunscreen in the past month, this was 41% ($n = 7$) at the end of the study. "Never" applying sunscreen in the past month was 44% ($n = 12$) in the first questionnaire, and 35% ($n = 6$) in the second. Furthermore, the majority of the participants reported that sunscreen provided by the employer (59%, $n = 16$ and 53%, $n = 9$, respectively), and sunscreen as protection against skin cancer (85%, $n = 23$ and 71%, $n = 12$, respectively) were encouraging reasons for using sunscreen at work.

Knowledge of Sun Risks and Behavior in the Sun

Table 3 presents the knowledge of OW regarding sun risks. At baseline, the majority of OW (82%, $n = 22$) knew that sun exposure is the primary cause of skin cancer, this percentage was 100% ($n = 17$) after the installation of the dispensers. Furthermore, almost every OW knew that sunscreen is still important even if you have a tanned skin (96%, $n = 26$ and 88%, $n = 15$, respectively). For approximately two thirds (63%, $n = 17$ and 65%, $n = 11$, respectively) of the OW, the use of sunscreen at work is of importance, and for 67% ($n = 18$) and 82% ($n = 14$), respectively, it is easily fitted into the working day. In **Figure 2** is shown that the majority of OW has not had a sunburn in the previous 3 months during work (71%), as well as during leisure time (77%).

Facilitation of Sunscreen Dispensers at Worksite

OW were satisfied regarding the sunscreen dispensers placed on the worksite: 65% ($n = 11$) agreed that the dispensers were easy to use, and 59% ($n = 10$) agreed that the dispensers were located in practical spots. Sunscreen was not seen as a nuisance during work by 47% ($n = 8$), and 53% ($n = 9$) found the sunscreen easy to apply and not sticky. Information on posters helped 53% ($n = 9$) of OW to use sunscreen, and a majority of OW (65%, $n = 11$) would recommend the dispensers and posters to colleagues. When used, sunscreen was mostly applied to the face (94%, $n = 16$), and in lesser amounts to the arms, legs and chest/stomach/back. See **Appendix III** for Figure.

Sunscreen Consumption

Nine sunscreen dispensers were installed at strategic places at the construction site for 14 weeks, i.e., 71 work days. The dispenser used most was placed at the exit of the canteen, second at the entrance of the canteen and third was the dispenser placed at the entrance of the changing rooms. Least used dispensers were placed next to the outside smoking area and in the scaffolder's office.

Interviews With Managers Regarding Sunscreen Dispensers

The interviews with the managers revealed a variety of experiences. Overall, the conclusion was that the sunscreen dispensers were a positive asset to the construction site and the dispensers as well as the sunscreen were easy in use. However, differences were found in their opinions whether dispensers are the optimal way of offering sunscreen. Also, the scaffolder's manager said "The scaffolders are wearing a lot of personal protective equipment (including mouth masks), so there is not much skin left to apply sunscreen on," suggesting that scaffolders are not the optimal pilot group for stimulating sunscreen use. Lastly, the sunscreen dispensers were very similar to the hand disinfection gel dispensers, resulting in some OW mistakenly applying sunscreen when they initially wanted to use hand disinfection gel.

Part 2: UV-Biomarkers

Urocanic Acid Isomers

Figure 3A shows that the relative amount of cUCA was not significantly different between OW and IW. However, there was a significant difference between the levels of cUCA measured in IW between the forehead and behind the ear. The concentration of cUCA in OW were similar for the forehead and behind the ear, both reaching a level of 63%.

Immunological Markers

Figures 3B–J shows the levels of various immunological markers in OW and IW, measured in the SC sampled from the forehead and behind the ear. None of the fifteen included immunological markers (not all presented) showed significantly different levels between OW and IW. Comparison of the two investigated skin sites revealed that concentrations of IL-18, IL-8, IL-1α, IL-1RA and the ratio of IL-1RA/IL-1α were significantly different between the sun-exposed and less exposed sample locations (i.e., forehead and behind the ear) for OW as well as IW. VEGF was only significantly different between the forehead and ear in OW (**Figure 3G**).

DISCUSSION

This pilot study revealed low sunscreen use among OW, despite providing sunscreen at the workplace, overall satisfaction with the sunscreen, and sufficient awareness of the risks of UVR exposure. The collection of SC samples at the workplace is feasible, and several UV-biomarkers showed to be promising in assessing UVR exposure. Several method- and intervention-related elements of a future intervention trial were investigated, the elements recruitment and (loss to) follow-up need more attention since the participation rate was low and the loss to follow-up high.

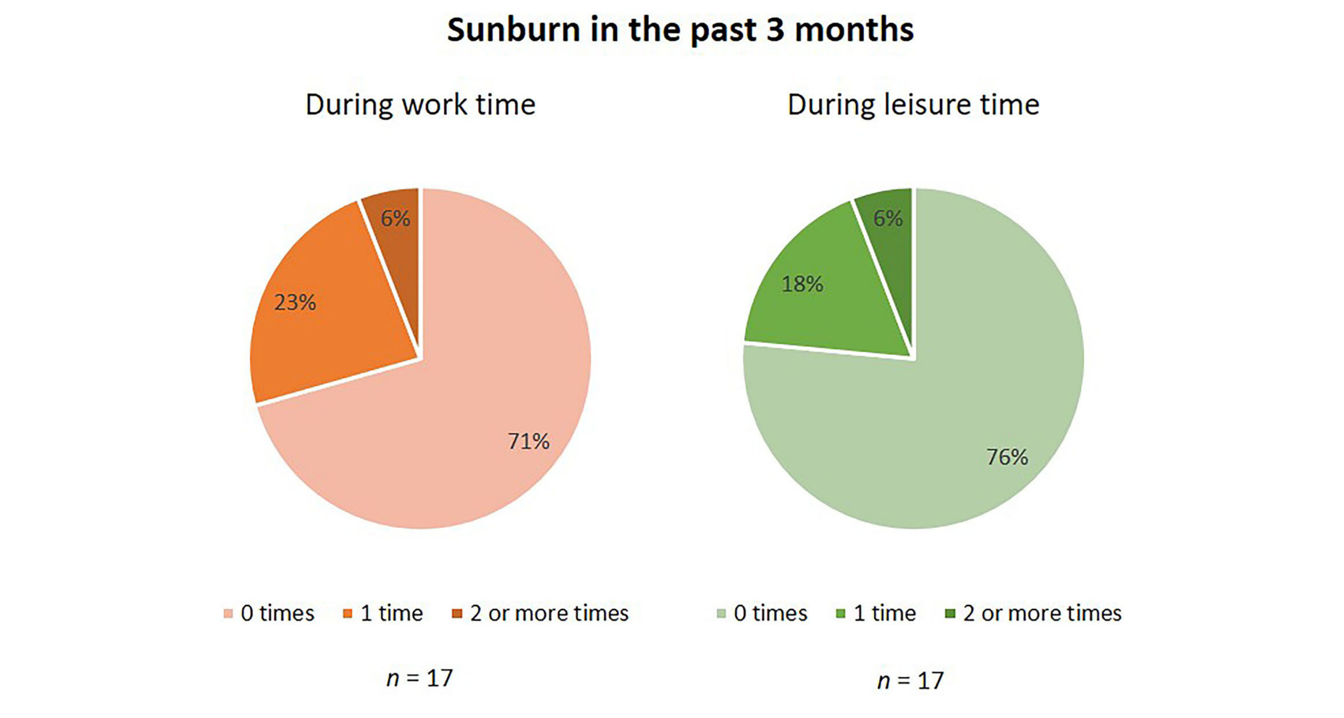

FIGURE 2 | Sunburn in the past 3 months. Numbers are percentages (%). Assessed in questionnaire 2 ($n = 17$).

Part 1: Sunscreen Use

This pilot study revealed low sunscreen use among OW, although the number of OW who reported never using sunscreen in the previous month somewhat decreased (44.4–35.3%) after placement of the sunscreen dispensers. Low usage of sunscreen is in accordance with several other studies. In a study of Zink et al. (34), almost half of the participants reported that they seldom or never used sunscreen at work. Grandahl et al. (35) found that 33% of the OW rarely or never used any type of sun protection at work. Peters et al. (36) found that sunscreen use was low especially in male OW. Consistently, a systematic review by Reinau et al. (37) showed that OW have poor protection against UVR exposure at work, concluding that a vast majority of agricultural and construction workers rarely or never applied sunscreen at work. A possible reason for the low usage of sunscreen by OW in the present study might be caused by the rainy weather during the study period as compared with the average number of sunny days in the same period in previous years (38). Furthermore, approximately two thirds of the participants in this study reported that they wear protective clothing during work. According to the safety manager, the workers are obliged to wear hard hats, long-sleeved shirts, and—because of the pandemic—a face mask, which left the exposed skin area small. Behavior concerning the use of protective clothing among OW is largely dependent on the safety requirements of the employer and differences between studies are large. For example, Peters et al. (36) found that 82% of the OW wore protective clothing in the form of long-sleeved shirts while a systematic review of Reinau et al. (37), reports percentages of OW wearing protective clothing between 20 and 50%. Another factor that might have an influence on sunscreen use, is the time spent outside: in our study approximately one third of the OW worked outside for <4 h per day. The combination of wearing protective clothing and spending less time outside might have contributed to the low occurrence of sunburns in our study. The majority of OW never had a sunburn during work in the past 3 months, while other studies reported the opposite: 50–80% of the OW had a history of sunburn at work (35, 37).

We asked the OW for their knowledge on the risk of skin cancer, believes on sunscreen use, and protection measures as this information might be useful for setting up an intervention. A vast majority of OW in our study was aware that UVR exposure is the primary cause of skin cancer, that they have to apply sunscreen when it is overcast, and that a tanned skin is not a reason to stop using sunscreen. This is consistent with other studies where OW had good knowledge of skin cancer facts (34, 37). It is encouraging that the majority of OW in our study reported that sunscreen use is easily fitted into the work day, whereas Zink et al. (34) found that 50% of the OW had difficulties implementing these measures into their routine. Sunscreen provided by the employer at various easily accessible places at the workplace encourages sunscreen use, reported OW in this study. Furthermore, they rated the sunscreen as easy to apply which is important information for future intervention studies.

Part 2: UV-Biomarkers

Collection of SC samples at the workplace showed to be feasible. Duration of sampling was ∼5 min per participant and the

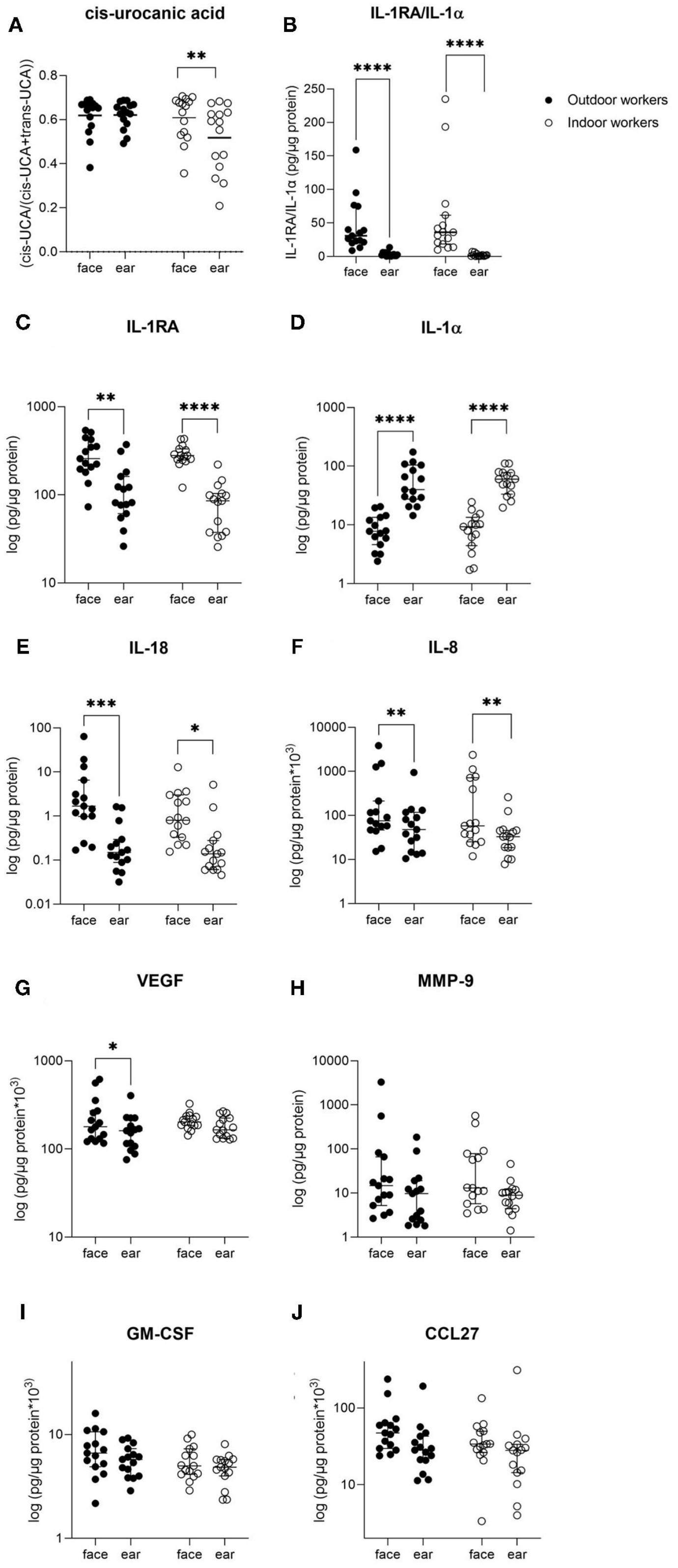

FIGURE 3 | Overview of stratum corneum concentrations of several markers measured in outdoor and indoor workers. Data are presented as median with interquartile ranges. Differences in concentrations between both groups were tested using Mann-Whitney *U*-test. Differences in concentrations between sample locations (forehead and ear) were tested using Wilcoxon ranking tests. **p* <0.05, ***p* <0.01, ****p* <0.001, *****p* <0.0001.

participants did not experience any discomfort. As expected, several immunological markers showed a significant difference between the two investigated skin sites. The differences in levels of immunological markers between OW and IW was not significant, however, several markers such as IL-18, IL-8, CCL27, and GM-CSF showed a pattern of higher values in OW compared with IW. It has to be noted that these IW were not the ideal control group as some of them just returned from holiday and likely had high exposure to UVR. In future intervention studies where intervention (with sunscreen) and control groups (without sunscreen) will be compared at different time points during the study, a larger difference in levels of immunological biomarkers may be expected.

cUCA levels in IW were higher in the sun-exposed skin site compared to the less exposed skin site, but in OW cUCA reached a saturation level of approximately 60% in both investigated skin sites. cUCA is formed from tUCA upon exposure to UVB in a dose-dependent manner until reaching a photo stationary state at ∼60–70% of total UCA (39). Whether cUCA is suitable to assess the effect of sunscreen use will largely depend on the degree of reduction in UVR exposure (i.e., UVR exposure under the cUCA saturation level). It should be kept in mind that the relative amount of cUCA in the unprotected and chronic UVR exposed skin will likely reach saturation level and only a qualitative measure of the difference between two groups can be obtained.

The finding that immunological markers differ in levels in the two differently exposed skin sites is encouraging and confirms our previous data (22, 23) that they might be particularly useful to assess chronic exposure to UVR. Furthermore, they are also important for assessing the immune response in the skin which plays an important role in UVR mediated damage (40) and might even occur before visible changes (erythema of the skin) are seen. Several immunological markers investigated in this study seem to be suitable to assess those effects of UVR exposure (41–44).

Lessons Learned From This Pilot Study: Strengths and Limitations

In this pilot study we investigated the feasibility of several elements (i.e., recruitment, (loss to) follow-up, outcome measures, data collection, and the acceptability of the intervention) which revealed some challenges that need to be addressed. First, the number of OW that was willing to participate in this study was much lower than we expected. After recruitment, 67 construction workers were eligible for participation in this study, but only $n = 27$ participants completed the first questionnaire and even less ($n = 17$) completed the second one. In a post-study interview, the site managers recommended to communicate the relevance of sun-safety behavior clearer to the OW by using other communication channels. As suggested by the site managers, visual aids, such as an UV-lamp, showing the skin damage already present in their faces, or offering skin checks by trained physicians for signs of sun damage or skin cancer might be more effective to motivate OW to participate in the study. Second, the selection of eligible outdoor construction workers for participation in a study stimulating sunscreen use has to be accurate. In this study we also included scaffolders who wore substantial amounts of personal protective equipment, which left almost no skin parts free for sunscreen application. Consequently, we probably have a lack of urgency for using sunscreen during worktime in our pilot group. In future studies, a longer study period would compensate for fluctuations in outdoor work tasks at a construction site. Furthermore, construction workers who wear lesser amounts of personal protective equipment (i.e., more exposed skin area) will be included. Third, we encountered a language barrier since the majority of the construction workers did not speak Dutch or English (despite English being the official language at this construction site), making it difficult to verbally inform or answer questions. Having a "workplace champion" to serve as a contact person at the study site during the project with good command of English and/or Dutch, and the mother tongue of the group of OW would improve verbal communication, since the number of foreign nationals working in construction is increasing (45). Fourth, it is recommended to also collect the opinions of several stakeholders—including the OW themselves—on what is needed to make OW more aware of sun-safety behavior during worktime with, for instance, a focus group.

Fifth, our study period of 16 weeks might have been too short to achieve behavior change. It is reported that longer duration of the study probably has more chance to lead to change in behavior (46). Particularly important to mention for this pilot study is the rotating system that was used at the construction site: OW worked for 2 months followed by 1 month time off. This might have influenced on their commitment in participating in a 4-month study. For future intervention studies it is recommended to select OW who remain at the same construction site for a longer time. Sixth and last, the low usage of sunscreen indicates that providing sunscreen at easily accessible places at the workplace as standalone intervention is not enough to increase sunscreen use among OW substantially. The message to use sunscreen during work should be repeated continuously. For example, by implementing structured feedback on sunscreen use at that specific workplace in order to motivate and improve compliance (47). This message should be produced in a colorful and illustrative format which helps to transmit it more effectively (45, 48). Lack of awareness on the risks of UVR exposure, common misbelieves such as "people with a tanned skin are not at risk for skin cancer", and concerns regarding the interference of sunscreen with work activities were not identified as barriers among participants in this study. Additionally, we removed common barriers such as availability, accessibility, and costs of sunscreen (9, 20, 21) by installing sunscreen dispensers at strategic places at the construction site.

In this pilot study, the installation of sunscreen dispensers at strategic places at the workplace encouraged sunscreen use among OW. Regarding the acceptability of the intervention, OW reported that they were satisfied with the dispensers as well as the sunscreen, and that it did not interfere with their work tasks. This is an important finding, which means that this intervention can be continued in future studies. Furthermore, the questionnaires were a feasible tool when presented as an online platform, so participants were able to complete the questionnaire on their smartphone or computer. Also, the use of QR codes (quick response) appeared to be feasible. Additionally, it is important to make the questionnaires available in several languages, in order to avoid a language barrier. A limitation, as always for self-completed questionnaires, is that a recall bias or social desirable answers cannot be excluded. Lastly, with the UV-biomarkers we have found a feasible tool to use at the workplace for assessing the internal UVR dose (i.e., UV-dose absorbed by the skin). Collection of SC samples is easy, simple, and painless for the participant. For future intervention studies, we recommend to also measure the external UVR exposure using personal dosimeters to get more insight in the UV-exposure pattern during the work shift and different work tasks.

In summary, this pilot study revealed that three of the investigated elements (i.e., outcome measure, data collection, and the acceptability of the intervention) are feasible. Providing sunscreen dispensers at the workplace seems feasible, but not as standalone intervention for stimulating sunscreen use. Collecting SC biomarkers of UVR exposure at the workplace is feasible and the markers showed to be promising in assessing UVR exposure. However, the elements recruitment and (loss to) follow-up need more attention since the participation rate was low and the loss to follow-up high. This poses a challenge for future intervention studies.

DATA AVAILABILITY STATEMENT

All relevant data is contained within the article: The original contributions presented in the study are included in the article/**Supplementary Files**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Medical Ethics Committee of the Academic Medical Center, Amsterdam, the Netherlands. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AK was largely involved in the conception, design, and operational management of the study, was responsible for conducting the study and the (biochemical) assessments during the study, and prepared the manuscript. SK has expertise in skin bioengineering methods for the assessment of stratum corneum samples, was involved in the conception, design and supervision of the trial, and was involved in drafting the manuscript together with AK. HM brings expertise in occupational health, pragmatic research, and translating research findings into policy and was involved in the conception and design of the trial, and drafting the manuscript together with AK. TR brings in expertise in dermatology, pragmatic research, and critically reviewed the manuscript. CH brings expertise in occupational health, pragmatic research, and critically reviewed the manuscript. All authors read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.857553/full#supplementary-material

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Probing Different Approaches in Ultraviolet Radiation Personal Dosimetry – Ball Sports and Visiting Parks

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Solar ultraviolet radiation (UVR) continues to be a decisive influencing factor for skin health. Besides acute damage (e.g. erythema), chronic light damage is of particular relevance. Skin cancer can develop on the basis of this light damage. Knowledge about irradiation is crucial for the choice of preventive measures, but has so far been incomplete in many occupational and leisure activities. Often a methodological problem in study design is the cause. Here we report on the clarification of two issues. First, further values are to be determined on the way to a comprehensive exposure register of leisure-related activities. Furthermore, it is to be determined to what extent the measurement setting can have an influence on the measurement campaigns. For long-term measurements, football referees were equipped with dosimeters over several months, selective measurements during visits to parks were carried out by on-site recruitment of test persons. It turned out that the choice of method also depends on the expected compliance of the test persons. Long-term measurements of specific activities such as playing football are particularly suitable for observing the course of UV exposure over the year and generating resilient mean values. Point measurements such as visits to parks can also do this if there are enough such events spread over the year. However, they are particularly suitable for such on-site campaigns, as they may be combined with awareness campaigns of the issue of skin cancer. They also allow many measurements to be taken at the same time in one place. Both playing football and visiting parks are associated with high levels of radiation, so specific prevention concepts need to be developed. We were able to determine that the sunburn dose for light skin types was reached or exceeded for both of the investigated activities.

Keywords: UV radiation, personal dosimetry, personal exposure, health prevention, exposure registry

INTRODUCTION

Ultraviolet (UV) radiation has been known to be a complete human carcinogen for many years and was classified by the International Agency for Research on Cancer (IARC) in Group 1 ("carcinogenic to humans") as early as 1992 (1). UV radiation has a broad spectrum of effects on the human body, both beneficial and harmful. UV radiation is essential for the production of vitamin D3 (2, 3) but causes short-term (e.g., sunburn) as well as long-term (e.g., skin aging) damage if the exposure is too high. Chronic light damage can result in skin cancer; this includes various entities with different causative mechanisms, but all directly related to UV exposure. Squamous cell carcinomas (SCC) and their precursors, actinic keratoses (AK), are caused by cumulative UV exposure (4), while basal cell carcinomas (BCC) are likely related to the intensity and duration (intermittency) of UV exposure (5). Statistically, these entities have a ratio of 4:1:10 (BCC, SCC, AK) (6–8).

People are permanently exposed to UV radiation, both in their leisure time and their work environment. The latter, in particular, can lead to extremely high levels of irradiation, which require special medical screening (9). As a rule, employees do not have the possibility to choose whether or not they are exposed but are forced to rely on preventive measures. Several papers have already dealt with this topic in the past (10–16). To ensure comprehensive protection against UV radiation, a holistic approach for prevention is of great importance. This, therefore, includes leisure time activities.

It is of great importance to know what the actual irradiation is in order to be able to assess the risk and implement the appropriate measures correctly. The use of standardized, suitable measurement technology significantly contributes to acquiring this knowledge. While polysulphone film dosimeters (PSF) or biological spore dosimeters were often used in earlier measurements of personal UV exposure (17–20), more recent studies focus on the use of electronic data logger dosimeters (10, 12, 21–23). Comparative studies have clearly shown the latter's advantages (24).

Many studies on individual leisure time activities and the corresponding UV dose already exist. An overview of these has been provided earlier (25), while the behavior of sunbathers was studied, for example, in detail (26). Three groups were identified: suntanned, non-suntanned and photosensitive individuals. The personal UV doses of the groups were 259 J/m², 236 J/m² and 204 J/m², respectively, within a maximum measurement time of 134 min at noon. The ambient UV doses were also measured and averaged 1249 J/m², 1202 J/m², and 1121 J/m², respectively. In a study by Sun et al. (27), measurements of UV exposure in the population were conducted in Australia. For this purpose, participants were asked to wear polysulphone film dosimeters on their left wrist for 10 days. This took place at four locations (Townsville, Brisbane, Canberra and Hobart) and at four seasons. The average values of the personal UV dose per day range from 30 J/m² to 200 J/m² in the different seasons and locations. There is a study from 2007 for the activity "playing football" (28). This study involved fitting dosimeters to the faces of schoolchildren in Australia and having them play games of basketball and football for 1 hour. This resulted in average UV exposure of 99 J/m² to 140 J/m².

Several other studies have focused on determining the UV exposure doses received during specific activities like cycling, jogging and hiking (16, 17, 29–34). They differ mainly in the selection of the participant collective, the measurement technology used, the duration of the measurement, and the selection of the activities studied. Intercomparison is possible, but with certain assumptions regarding systematic deviations (24) and time and geographical particularities. Our study was designed in a way to cancel out intrasystematic deviations regarding the measurement technology and statistical uncertainties due to small sample numbers.

This study addresses two questions. The first is to determine additional values as part of a comprehensive exposure register of leisure-related activities. The second is to determine how the measurement setting can influence the measurement campaign itself. Basically, different approaches for obtaining data according to specific activities may be of use: either the participants are equipped with dosimeters over a long period of time and measurements are performed during a specific activity, or alternatively, an activity can be measured specifically on individual days with a large number of test persons simultaneously. For leisure time exposure, for example, public or sporting events are suitable. We chose football and visiting parks/recreational trips as a good way of addressing the research questions.

MATERIALS & METHODS

Test Person Collectives and Measurement Locations

In the run-up to the measurements, we consciously opted to select two activities that, in our view, are particularly appropriate and provide an excellent example of the leisure behavior of the "general public." These activities are football and visits to parks. Football was chosen because it is a ball sport that is widely played and, in a broader sense, can also be used as a symbol for other ball sports. Furthermore, this activity is practiced all year round. The German Football Association (DFB) was called on to help recruit participants. Under FIFA and DFB rules, there are strict regulations regarding items worn on the body during training or matches. Consequently, it was not possible to equip players themselves with dosimeters. This regulation does not apply to the same extent to referees or coaches of the amateur leagues, so these two groups were asked to wear the dosimeters during the course of our measurements. Referees, in particular, move around the pitch in the same way as players. The movement pattern is also comparable to coaches during training. Furthermore, measurements could be taken at some special events such as tournaments, where several short matches took place on 1 day. The measurements took place in 2018 and 2019, from May to October in each instance. The possible measurement times were 4:30 p.m. to 9:00 p.m. from Monday to Friday, and 10:00 a.m. to 9:00 p.m. on Saturday and Sunday. In total, 33 people participated actively (16 in 2018 and 17 in 2019).

For the centralized single-day measurements at a large event, covering the leisure time activity "visiting parks", the aim was to equip as many volunteers with dosimeters as possible at the same time and for a whole day. The measurements were performed on specific days during a federal garden show (Bundesgartenschau) that took place from April to October 2019 in Heilbronn, Germany. In total, measurements were done on 5 days during this period. More precisely, the measurements each took place on 1 day in April, June, and August and on 2 consecutive days in September (17/04, 18/06, 27/08, 20/09, 21/09). A prerequisite for the measurements was to have stable and dry weather conditions. For each measurement day, 15 dosimeters were available that were randomly distributed to interested visitors of the garden exhibition. The participants were recruited after entering the event and returned the dosimeters before leaving. On account of this, the measurement duration varied between the volunteers and the measurement days. Ambient UV exposure was also recorded at the same time. Hence, exposure conditions could be calculated from the ratio between ambient and personal UV exposure (18). The participants were told to behave as they would normally do, but an influence of the behavior cannot be completely ruled out (Hawthorne effect). Theoretically, two opposing effects are conceivable: First, people may spend more time in the sun than they normally do, second, people may seek more shade than they normally do. Both would give a footprint in the gyroscope data by time intervals of resting with simultaneously high or very low exposure data – both could not be detected. From our experience with 1,000 participants in another UV study, we received numerous proves that participants “forgot” the dosimeter after a certain time while wearing them; this might be attributed to the location where the device was worn in combination with its light weight.

Exposure Measurement Technique

The participating volunteers were equipped with the GENESIS-UV measurement technology, consisting of an electronic dosimeter for measuring personal UV exposure and a tablet PC to regularly transfer the measured data to the Institute for Occupational Safety and Health. During the “visiting parks” activity, the researchers conducted the latter task immediately after the measurements were taken so that no other technology needed to be given to the participants.

The personal UV exposure was measured via electronic dosimeters of the type X2012-10 V3 from Gigahertz Optik (Türkenfeld, Germany). Our GENESIS-UV system for decentral UV exposure measurements has been described earlier (10). In brief, the dosimeters use two separate UV sensors (one for UV-A and one for UV-B/C) to measure the UV radiation erythema-weighted to a maximum resolution of 1 s. Erythema-weighting is achieved by built-in filters which reflect the spectral sensitivity of the skin to develop erythema. The erythema action spectrum S_{er} has been defined by the International Commission in Illumination (CIE) and is anchored in international standards (35). This provides detailed information about the exposure. Any average values for any condensed time interval can be calculated based on the per-second values. For reasons of checking data reliability, the dosimeters contain gyroscopes. By analyzing the accelerometer data from the gyroscope, information can be obtained to determine whether the dosimeters were accelerated or were resting. This can be a way of checking whether or not the dosimeters were worn properly while the measurements were taken. The devices were attached to the left upper arm via a tissue strap.

Stationary Measurements and Data Analysis

An additional dosimeter was used to record the ambient UV radiation for the measurements taken during the visits of the garden exhibition. This dosimeter was mounted horizontally on a pedestal in the park, free from shading.

Stationary measurements are particularly important for measurements on a few individual days in order to put the personal measurements into an overall context. In contrast to spore or polysulphone film dosimeters, the choice of electronic dosimeters also allows the measurement and resolution of a temporal sequence over the course of the day. This can significantly help determine whether people’s behavior changes at times of exceptionally high UV exposure (such as mid-day).

Since the dosimeters have a cosine dependence for detecting UV radiation, the resulting curve of ambient radiation is a combination of the radiation from the sun and the cosine of the angle between the sun and the detector normals.

In order to achieve intercomparability of the measurement results, the ratio between personal (UV_{pers}) and ambient (UV_{amb}, incoming radiation on a flat horizontal surface over the same exposure time period of personal exposure) UV exposure was calculated (exposure ratio to ambient, ERTA) (18). The ERTA is expressed as a percentage and calculated as follows: $\frac{UV_{pers}}{UV_{amb}} * 100\%$.

This ratio has previously been estimated to be approximately 3% to 5% as an annual average and about 30% while being outside during the day (36). As described in their publication, the dosimeter was worn on the forehead, which is comparable to our positioning of the dosimeter on the left upper arm (37). Accordingly, our measured values can be used directly to calculate the ERTA without positional conversion.

The UV radiation data and the motion data of the accelerometer were evaluated in relation to each other for data analysis. Any areas in the data that did not show simultaneous movement were removed. The assumption could be made that the dosimeter was not worn on the person at these times. A procedure was also used to recalibrate the data with respect to dosimeter calibration, longitude-time correction and similar factors. After processing the raw data, the data available at one-second intervals were combined into intervals. Every 60-s measurement interval was totalled to get a minute value. Incomplete minute intervals at the beginning and end of a measurement series were ignored.

Comparison With Yearly and Daily Variations in the Solar Irradiance

Global radiation is subject to both an annual and a daily cycle. It makes sense to analyze the data acquired in comparison to this. The distribution of UV irradiation over the year or over the day from an earlier publication is used for this purpose (11). The values are also related to the month of the solar maximum in June in order to make a relative comparison of the months easier. Given that the reference to the diurnal patterns will only serve as an illustration, this conversion is not necessary. **Supplementary Figure 1** shows the corresponding curves and indicates the corresponding values under the histograms.

The measurements of the measurement campaign do not span the entire year, so the missing period must be extrapolated based on the seasonal factors. Assuming that the investigated activities were carried out in the same way in the missing period, a linear extrapolation can be carried out for the required periods.

RESULTS

Long-Period Measurements: Football Games

In total, the football referees accumulated 35,372 min of measurement on 237 measurement days. **Figure 1A** shows the UV exposure for a football game in the month of July. This shows the two half-times with a break, which was obviously spent indoors. This behavior can be observed in most measurements for "playing football." The course of the measured values provides detailed information on personal UV exposure during a football game. A clear distinction between active and resting (pauses) phases can be seen when taking the data from the accelerometer into account. Resting phases are identifiable by values of |a| around 1, which corresponds to the accelerometer experiencing only earth's gravity. The highest UV exposure dose (406 J/m^2, i.e. 4.06 SED; 1 SED equals 100 J/m^2 erythemal weighted irradiance) was measured during a football game taking place in July around noon in the early afternoon. By combining these data of several matches taking place in different months to a single plot, the differences in the data course and in UV exposure can be distinguished more clearly (**Figure 1B**).

In direct comparison to a football match taking place in June at approximately the same time and with comparable duration with a total UV exposure dose of 214 J/m^2, the UV exposure is almost 2-fold higher in July. Comparable results for the total UV exposure dose can be seen for football matches in May in the afternoon (179 J/m^2) and October beginning from noon to the early afternoon (179 J/m^2).

Figure 2 shows an example of a measurement day on which one person conducted several short games in succession. It can be seen that the irradiation during the individual games follows the course of the sun and the theoretically expected daily values, ultimately culminating at noon. The individual exposure doses also increase, from 25 J/m^2 at 11:15 a.m. to 103 J/m^2 at 2 p.m. The total daily exposure dose is 543 J/m^2. In this instance, the rest periods were not spent indoors but presumably in a shaded area or under a pavilion. The exposure during these times is 89 J/m^2 in total.

Single Day Measurements: Visiting Parks

On the five days of data acquisition for the "visiting parks" activity, a total of 75 measurement days were achieved (5 days times 15 dosimeters) to a total of 23,777 minutes. **Figure 3** shows data acquired at "visiting parks" as the average UV radiation of all 15 volunteers per minute over the whole day for 1 day in April (17/04/2019) and 1 day in September (21/09/2021), plotted together with the ambient radiation detected by the dosimeter placed horizontally in the sun. The figure also provides information about total UV doses of ambient and personal measurements.

For the measurement day in April, a total ambient UV exposure of 1,287 J/m^2 and an average total personal UV exposure of 195 J/m^2 was recorded. For the measurement day in September, a total ambient UV exposure of 1,509 J/m^2 and an average total personal UV exposure of 252 J/m^2 was measured.

When the ambient UV radiation patterns of the different days are compared, some differences become immediately apparent. The basic shape follows the sun's path, with the sun's peak at about 1:30 p.m. The measurement in September illustrates this very well, as it was a mostly clear day with only a few clouds (can be seen as dips in the curve). The measurement in April was characterized by changeable weather, which can also be seen in the curve of the ambient UV radiation. This fluctuates much more throughout the day, as clouds of different thicknesses repeatedly shifted in front of the sun.

The average personal UV dose for the 15 individual measurements does not follow the course of ambient radiation throughout the day. This effect can be seen more clearly when plotting some of the individual measurements separately (**Figure 4**). Here, the measurement data of five randomly selected volunteers were plotted in comparison to the ambient radiation. It can be seen that individual measurements vary clearly in their temporal course, measurement duration and the resulting total UV exposure. The blue curve (participant 5) is interrupted at some point. In this instance, the participant took off the dosimeter, probably during lunchtime. On the other hand, the exposure of participant 3 (green curve) is close to zero for a lot of the time. This person was probably indoors during that time but correctly did not take off the dosimeter.

Derived Values

The resulting monthly mean exposure values per minute for both measured activities are given in **Table 1**.

To compare how the individual monthly irradiation values relate to the annual cycle of irradiation by the sun, we also related these values to the solar maximum in June. The calculated values are shown in relation to the expected mean ambient radiation. The mean ambient radiation is also normalized to the maximum expected to occur in June. It can be seen that for the long-term measurements during football games, the course of accumulated UV exposure doses, on the whole, follows the course of the expected mean ambient radiation, albeit being slightly higher than expected by the fraction of the ambient level. The maximum exposure is slightly shifted, giving rise to behavioral dependence to be discussed later. Single day measurements while visiting parks can only give limited information. The tendency of the values with regard to the ambient is not clear at first glance but can be explained when taking the ambient temperature into account.

The calculation of a yearly exposure dose is rather tricky when monthly averages are to be multiplied with the time spent executing the activity while the latter is unknown. Nevertheless, knowledge of the annual dose is of particular interest when comparing different activities. As the measurements were performed from May to October, the dose has to be extrapolated to the whole year. Concluding from **Supplementary Figure 1**, 78% of the yearly UV exposure is accumulated during the measurement period from May to October. The missing data was then calculated by summing up the values from May to October, then dividing by 0.78. For example, if football is played for

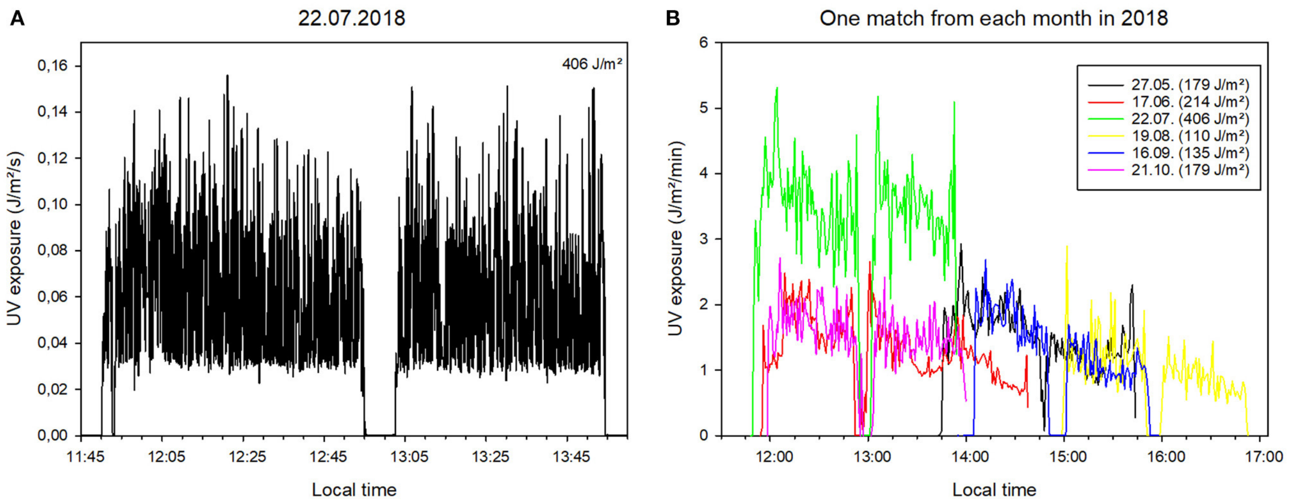

FIGURE 1 | Representation of individual measurements of UV exposure during football matches. **(A)** UV exposure over time for a selected football match on 22/07/2018. Data is given in 1-s intervals. **(B)** Direct comparison of personal UV exposure acquired during football matches at different times of the day and during the year. Data is given in 1-min intervals for clarity.

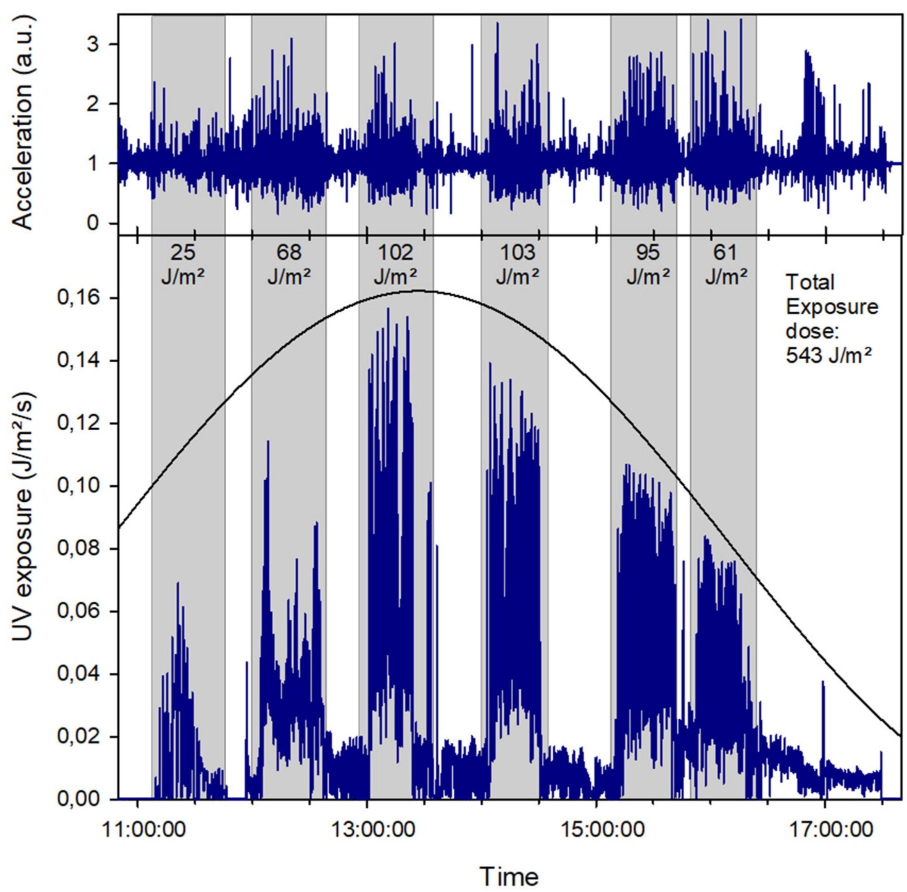

FIGURE 2 | Data from a competition that went on the whole day. Six matches were played during that time (marked by gray shading). For every single game, the respective irradiance is given. Total exposure doses gives the whole day exposure. The solid line represents the daily dependence of the global irradiance (without axis, only qualitatively) Top: accelerometer data; Bottom: UV exposure.

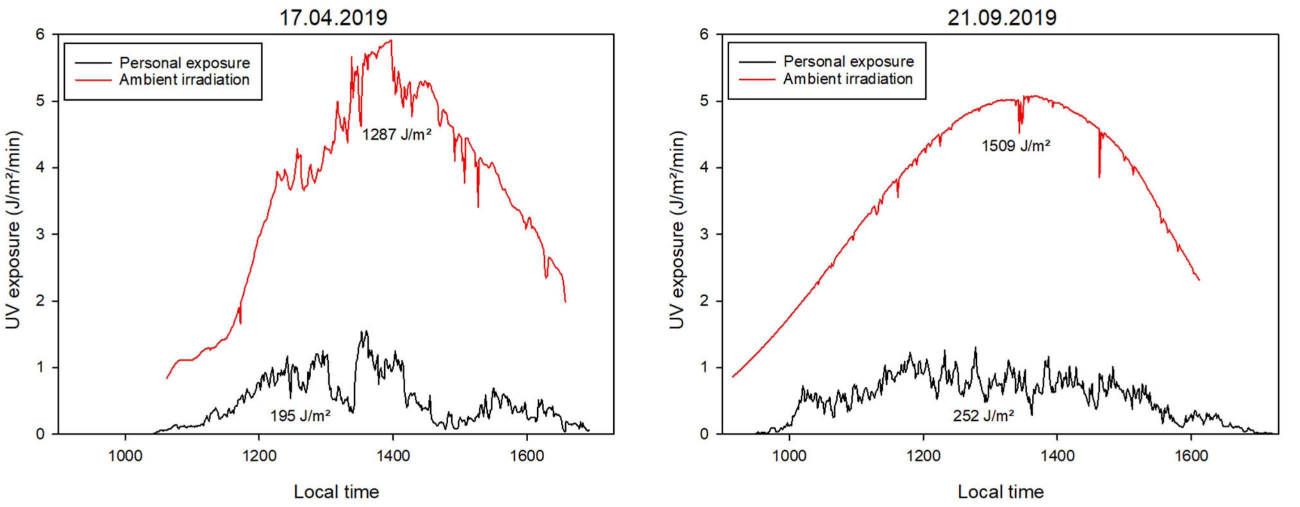

FIGURE 3 | Measurement data from the "visiting parks" activity from two different days. The red curves represent the ambient radiation on each day, measured with a separate dosimeter placed horizontally on a pedestal. The black curves represent the mean value of the personal exposure calculated from the 15 individual measurements. Also provided are total UV doses for ambient and personal measurements.

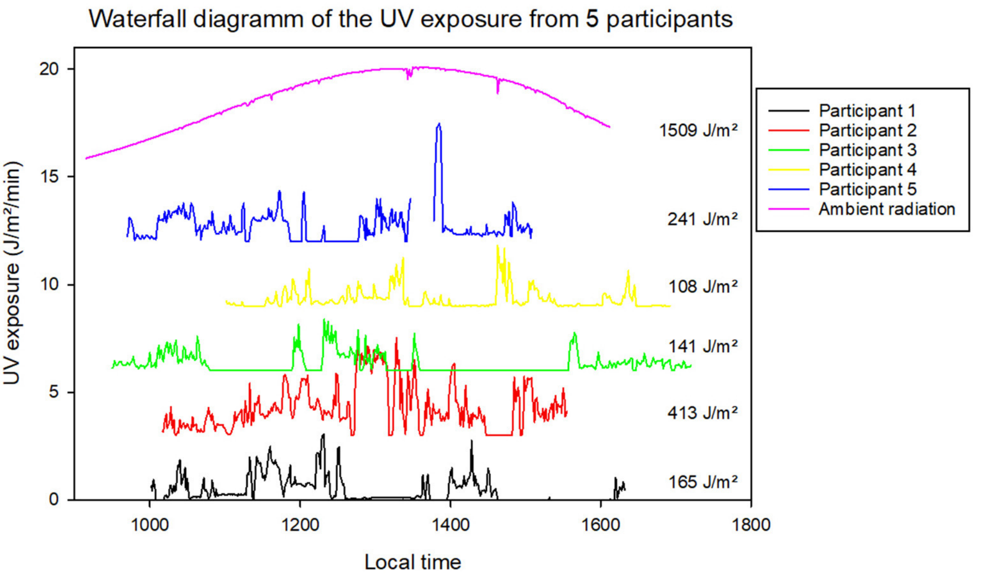

FIGURE 4 | Measurement data from five selected personal UV measurements for a single day on 17/04/2019 in comparison-related ambient radiation (in magenta). Ambient radiation was measured with a separate dosimeter placed horizontally on top of a pedestal. The measurements are displayed with offsets of 3 J/m²/min for clarity. The total UV dose per measurement is given on the right of each graph.

400 min each month (games and practice), the yearly exposure calculates to 2,831 J/m² (28, 3 SED). For visiting parks, a similar approach has to be chosen, taking into account that 52% of the annual exposure were covered.

Taking the approach of measuring lots of people simultaneously, determining and comparing the ERTA makes sense. **Supplementary Table 1** shows the individual measurement results for the daily accumulated total UV exposure doses for all 15 volunteers for the selected dates in April and September. Two examples are given in **Table 2**. The exposure ratio to ambient radiation (ERTA) was calculated for each volunteer. Additionally, the mean values for total UV doses and ERTA were calculated.

Individual total UV exposure doses vary significantly throughout the volunteers and the same applies to the calculated ERTA values. For the measurement day in April, personal UV doses vary between 61 and 351 J/m^2, corresponding to ERTA values between 8.8 and 37.8%. For the selected day in September,

TABLE 1 | Mean UV exposure doses per minute for both activities in every month together with their standard error values and total mean values.

		April	May	June	July	August	September	October
Football	Mean value [J/(m²* min)]	-	1.02 (± 0.01)	1.17 (±0.01)	1.21 (±30.02)	0.97 (±0.02)	0.76 (±0.01)	0.39 (±0.01)
	Normalized to the dose in June	-	0.87 (±0.01)	1 (±0.01)	1.03 (±0.02)	0.83 (±0.01)	0.65 (±0.01)	0.33 (±0.01)
Visiting parks	Mean value [J/(m²* min)]	0.82 (±0.01)	-	0.99 (±0.02)	-	0.57 (±0.01)	0.67 (±0.01)	-
	Normalized to the dose in June	0.83 (±0.01)	-	1 (±0.02)	-	0.58 (±0.01)	0.68 (±0.01)	-
Mean ambient radiation	Normalized to radiation in June	0.54	0.81	1	0.92	0.76	0.49	0.24

The monthly mean values are also normalized to the value in June. This was done in order to compare them to the mean ambient radiation (38) for each month, given in the last line. ("-": no measurements during this month).

TABLE 2 | Total UV exposure doses for the 15 participants at measurement days in April and September.

	17/04/2019		21/09/2019	
Volunteer #	**Total UV dose [J/m²]**	**ERTA [%]**	**Total UV dose [J/m²]**	**ERTA [%]**
1	61	4.7	256	16.9
2	189	14.7	165	11
3	149	11.	90	6
4	111	8.6	316	20.9
5	150	11.7	321	21.3
6	124	9.6	441	29.2
7	312	24.2	413	27.4
8	294	22.8	141	9.4
9	351	27.2	184	12.2
10	201	15.6	339	22.5
11	66	5.1	157	10.4
12	299	23.2	108	7.1
13	286	22.2	220	14.6
14	241	18.7	291	19.3
15	99	7.7	342	22.7
Mean value	195 (± 24)	15.1 (± 1.9)	252 (± 28)	16.7 (± 1.9)

Also calculated was the "Exposure Ratio to ambient radiation (ERTA)" and the corresponding mean values and standard error.

personal total UV doses vary in a similar range between 90 and 441 J/m^2, corresponding to ERTA values between 6.3 and 33.5%. On some days, the measurement of the ambient radiation started later or ended earlier than the measurements of some of the volunteers, so the ERTA was only determined for the times when a simultaneous measurement of the ambient radiation was available.

The measurement times of the volunteers ranged between 144 and 489 min over all days. The exposure lies between 61 and 603 J/m² and the ERTA is between 4.4 and 42.3%.

DISCUSSION

Measuring individual UV radiation exposure is both a technical and a logistical challenge. Selecting the measurement technology to be used is of central importance. Considerations in this context include the framework conditions, determined by the duration of the planned measurement campaign, as well as limitations such as the durability of the technology or the reproducibility of the results. Electronic data logger dosimeters, worn on the left upper arm, turned out to be ideal, proven systems for conducting long-term measurements of personal UV exposure (24).

Intrasystematic deviations occur when the measurement technique used is not sufficiently reliable and has a relatively large scatter. In order to arrive at suitable mean values, the use of a large number of measuring instruments is sufficient; however, an interpretation of individual results remains highly error-prone. We have followed both paths, namely the use of reliable dosimeters, as shown elsewhere (24), and the recruitment of a sufficient number of participants. Both characteristics are suitable means for long-term as well as single-day measurements to reduce deviations and uncertainties as far as possible. This is reflected by the low standard error values from descriptive statistics, as can be seen in **Table 1**.

Another question of equal importance is the timeframe in which the measurements should take place and what form of cooperation from the volunteers is necessary. There are two different approaches to this, each of which has both strengths and weaknesses. On the one hand, it is possible to recruit a large number of volunteers all at once at a specific place at a specific time; they then wear the dosimeters during their activities for a very limited period of less than a day. This method makes it possible to obtain a large number of measurements simultaneously in a very selective manner. Primarily, this allows direct comparison of the exposure data with regard to differences in the individual behavior of the participants since the same initial conditions (e.g., climatic) prevail for the measurements. In such cases, the volunteers' participation is based on an affect that results, for example, from being approached or being directly recruited at the measurement location. In such cases, it is advisable to only mention the requirement to wear the device within a certain period of time and specify where it is worn on the body. This was the approach taken during the visits to the garden exhibition, which resulted in daily measurements without the possibility of more precise differentiation (**Table 1**). The curves in **Figure 4** already show that the individual behavior of the test persons must have been very different with regard to the daily routine. As previously mentioned, it is not possible to make a more detailed statement about the activities included in this period. For this, the participants would need to keep some form of a diary at the same time.

This is different when measuring a specific activity over several months. Volunteers were recruited for this purpose without them being suddenly approached. The volunteers can find out about the measurement procedure beforehand and also select which activities they wish to engage in during the measurements – in this case, “playing football.” Consequently, it is reasonable to assume that the volunteers approached the measurements with a high level of compliance, at least at the beginning. Personal support and the ease of using the measurement technology meant that this could be maintained in the majority of cases until the end of the measurement campaign. This approach gives information on UV exposure during a specific activity over the course of a year (**Table 1**). Even from different volunteers, individual measurements are very similar (**Figure 1**). The accuracy and reliability of these measurements can also be detected indirectly in the data structure. For example, in each individual measurement, two time periods of equal length can be detected, interrupted by a short time interval. These are the two half-times and the break during a football match. The pitch check required of the referee – comparable to the warming up of the players – can also be identified from the data (**Figure 1** from 11:50 a.m. to 12:05 p.m.).

Each method has advantages and disadvantages, depending on the objective of the conclusion to be drawn (**Table 3**). Measurements over large parts of the year are advantageous because the annual course of UV radiation obviously does not follow the pattern expected from the distribution of global radiation (**Table 1**). Several such events must be distributed over the year to compensate for the disadvantages of single day measurements with many test persons in order to be able to make extrapolations of the course of the year with sufficient supporting points. We have used this in this study to make comparisons in different months. Ultimately, however, the activity to be studied also dictates which method is to be chosen. For a hobby such as playing football, it is relatively easy to recruit volunteers over a long period of time or to find volunteer collectives that change quickly. For visits to parks, it is easier to approach likely participants on site. When pre-selecting or recruiting volunteers, it is usually more difficult for people to predict the duration and frequency of visits of this kind throughout the year. If people are provided with measurement units for the whole year, there may be considerable periods when the units remain unused.

It is better to choose long-term measurements to derive an annual exposure value or the mean value over a longer period of time, as the behavior of test persons and the influences of secondary parameters such as weather can be better controlled. Measurement of personal UV exposure is largely affected by the personal behavior of participants (39, 40). Environmental and behavioral factors were both important in determining overall levels of exposure and distribution by site (33). For example, personal exposure is strongly affected by season (27). In the case of temperature, personal exposure increases first but seems to go down after a specific temperature is exceeded (41, 42). For leisure time settings, the fair-weather effect has to be named as probably one of the most determining factors: as in occupational settings, people working outdoors seldom have a chance to have an impact on outdoor exposure, it can be seen that during leisure time, people prefer to be outdoors when there is good weather. That is because leisure time exposure is consequently higher on average and, in many cases, higher than expected. In order to address this effect, we compared weather-related ambient UV levels to personal UV exposure levels by means of the ERTA. For this purpose, it makes sense to record ambient UV radiation, e.g. using another dosimeter in parallel to the personal measurements.

As reported, a person’s exposure ratio to ambient (ERTA) depends on the time spent outdoors and ranges between 3 and 5% on an annual average, but up to 30% during outdoor episodes (18). Our studies can confirm this (**Table 2**); only in 6 out of 75 cases the ratio of 30% is slightly exceeded (**Supplementary Table 1**). For the visit to the garden exhibition, no statistically significant correlation between the measurement time and the irradiation (dose) can be found (**Figure 5**). This clearly indicates that the behavior of people during visiting parks can differ significantly from person to person and thus lead to very individual patterns of exposure. In this respect, the approach of selectively measuring a large number of people for activities such as visiting parks, which ultimately comprise many smaller individual activities, is an appropriate choice to address this state of affairs. This is not the case for sporting events such as football, where a correlation can be found between measurement time or time spent outdoors and exposure (**Figure 5**). As a result, this indicates that these are typical exposure patterns for the activity.

This study, however, also provides further insights into the chosen activities over and above the methodological analysis, which can be of particular relevance as regards the field of prevention. It is evident that high UV irradiation levels can be acquired while playing a game of football, even if exposure times are short. Since people usually play wearing short clothing and often without headgear, the cumulative impact on the risk of skin cancer can be considerable. According to Fitzpatrick (43), any of the UV exposures identified are sufficient to cause sunburn, especially in fair skin types. The mean values given in **Table 1** can be used effectively to determine individual irradiation levels. An Australian study can be found in an international comparison (28). The irradiation of 99 $J/(m^2*h)$ to 140 $J/(m^2*h)$ measured in Hervey Bay (Australia, 25 °S) can be converted to German latitudes using latitude factors (11). Using a latitude factor of 2.4, a minute value of 0.69 $J/(m^2*min)$ to 0.96 $J/(m^2*min)$ is calculated. This agrees very well-with our values within the error limits.

TABLE 3 | Comparison of both approaches for measuring personal UV exposure.

Long period measurements	Single day measurements
Every participant has a dosimeter for several months	Participants wear the dosimeter only for a couple of hours
Participants need to read out the dosimeters and remember wearing it for the specified activity	No technical effort for the participant
Data gives strong statistics over long periods, average of weather and other environmental conditions is included in dataset	Very good statistics on single days in a specific location, but to contextualize these measurements to the course of a whole year more effort is needed (weather data, ambient measurement, etc.)
Long-term behavioral differences between people visible	Direct comparison of different people's behavior is possible
Data suitable for legal discussions and prevention conceptualization	Combinable with awareness campaigns of different stakeholders
Suitable for long-term or repeated intervention studies	Suitable for short-term or single-shot intervention studies

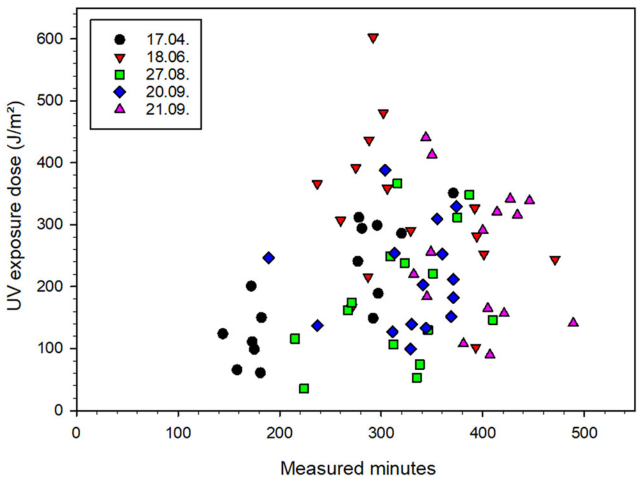

FIGURE 5 | UV exposure doses and total measured minutes for all participants of the "visiting parks" activity. The different measurement days are color coded, with 15 participants for each day. Each participant represents one data point. As an example, the red triangle on top represents a participant who took part on 18th of June, wore the dosimeter for 292 min and received an exposure dose of 603 J/m².

Although there is still no legally binding exposure limit value for UV exposure, let alone concrete legal policy plans, it is well-worth comparing it with the exposure limit values proposed by the scientific community. The World Health Organization (WHO) and the International Commission on non-Ionizing Radiation Protection (ICNIRP) (44) recommend a maximum daily exposure of 1 SED [1 SED = 100 J/m² erythema-weighted irradiation; incoming radiation weighted with the erythema action spectrum S_{er} from CIE (35)], which is about half to two-thirds of a sunburn dose for the vulnerable skin type I according to Fitzpatrick. In summer, in particular, this irradiation is reached very quickly if a person is active outdoors during the time of the highest exposures from 11 a.m. to 3 p.m. Sun protection measures should therefore also be taken into account for leisure time activities. This appears to be easier for activities in parks, as it is easier to install some forms of shade than, for example, on a football pitch. In the case of the latter, measures of prevention must be discussed with the football associations, the use of adapted clothing or sunscreen, which is suitable for the workplace and has been tested for employees who sweat heavily, appears to be individually possible and advisable.

This study has limitations. As the data set was recorded in Germany, checking the transferability to other countries and customs is necessary. The closer one gets to the equator, the stronger the UV irradiation becomes. As a result, the measured exposure values can vary, sometimes significantly, when measurements are taken in other countries or areas of the world. It should also be noted that the results obtained are, in principle, subject to the well-known problems of personal dosimetry but these have been primarily countered by using a large number of participants and a large number of data sets and validation methods. The most significant problems and inaccuracies were caused by the volunteers wearing the dosimeter incorrectly or putting the dosimeter down during measurements. The latter could be detected and corrected by also taking into account the measured values of the acceleration sensor integrated into the dosimeter. However, it is not possible to completely exclude errors due to incorrectly wearing the dosimeter. In the case of movements that are somewhat random with respect to the orientation to the sun, we expect the incorrect wearing of the dosimeter to have only a small effect on the data, provided that the measurement time is sufficiently long. It is important to ensure that the volunteers are thoroughly instructed and supervised when conducting such studies. Another factor to consider is the possibility that the volunteers' compliance may decrease, especially if the study is conducted over a longer period of time. However, this does not necessarily lead to poorer data quality but only to a possibly lower number of measured values. Again, for this project to be successful, it is essential to provide personal supervision and contact, not only at the beginning and end of the measurements but also throughout the whole course of the project.

Skin cancer caused by UV radiation continues to be a major issue, both in the occupational and leisure spheres. Our measurements have shown that in the recreational sector, considerable UV exposure doses can be reached even after a short period of time, which ultimately contribute to chronic light damage to the skin. It is important to counter this, firstly by measuring outdoor activities consistently as a basis for developing individual prevention approaches, which in turn provides evidence of the existence of the risk, and secondly by raising awareness, also by means of local events that provide information and measurements of individual exposure. This study serves both of these objectives and serves as a model for future measurements with related questions.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TH and MW: conceptualisation and project administration. TH, CS, and MW: validation and writing – original draft preparation. TH: data curation and investigation. MW: writing – review, editing, and supervision. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.868853/full#supplementary-material

Supplementary Figure 1 | Theoretical values for seasonal and daily dependence of UVR global irradiance. (a) Seasonal factors for the global UV radiation for every month throughout the year (northern hemisphere). The factors for the southern hemisphere are shifted by 6 months. (b) Daytime factors for the global UV radiation throughout a day in temperate climate during summertime. Data taken from (11).

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Sun Protection Behavior in Danish Outdoor Workers Following a Multicomponent Intervention

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Background: Outdoor workers can be exposed to relatively high levels of ultraviolet radiation and are at risk of developing occupational skin cancer. Implementing the use of sun protection in outdoor workers at work is therefore important. The objective of this follow-up study was to evaluate the effect of a multicomponent intervention to improve the use of sun protection in Danish outdoor workers.

Method: A total of 237 Danish outdoor workers were asked to complete surveys in 2016/17 and in 2020. Multicomponent interventions, between surveys, included information on skin cancer risk and use of sun protection, personal dosimetry and skin examination for signs of photodamage and skin cancer. Survey items on awareness of occupational skin cancer risk and perceived importance of sun protection as well as availability and use of sun protection at work were compared and analyzed in relation to the multicomponent intervention.

Results: Overall, the use of sun protection at work increased significantly (composite score [95% CI] 4.0 [3.7, 4.3] in 2016/17 and 4.6 [4.3, 4.9] in 2020, $p < 0.001$). Sunscreen was by far the biggest contributor, and the only type of sun protection used at work, which changed significantly (often/always use 37% in 2016/17 and 52% in 2020, $p < 0.001$). The biggest influence on the increased use of sun protection at work seemed to be a significant increase in the awareness of occupational skin cancer risk (moderate/high 43% in 2016/17 and 63% in 2020, $p < 0.001$) and perceived importance of sun protection at work (moderate/high 69% in 2016/17 and 83% in 2020, $p < 0.001$).

Conclusion: The results of this study indicate that awareness of occupational skin cancer risk as well as the perceived importance and use of sun protection at work in Danish outdoor workers may be improved by means of multicomponent intervention.

Keywords: outdoor worker, occupational, sun protection behavior, skin cancer, intervention—behavioral, risk awareness, Danish

INTRODUCTION

Ultraviolet radiation is classified as a group 1 carcinogen by the international Agency for Research on Cancer, and is the main risk factor for developing skin cancer (1–3). Worldwide, the incidence of skin cancer has increased significantly in recent decades (4) warranting an increased focus on preventing solar ultraviolet radiation exposure.

Outdoor workers, in particular, can be exposed to relatively high levels of solar ultraviolet radiation and may thus be at increased risk of developing skin cancer. In Denmark, there are about 400 000 outdoor workers (5), and recent measurements in Danish workers have shown levels of exposure to ultraviolet radiation in outdoor workers that are approximately four times higher than that of indoor workers (6). Outdoor workers in several other European countries are similarly exposed to relatively high levels of occupational solar ultraviolet radiation (7, 8).

In two systematic reviews from 2011, outdoor workers were shown to have a significantly higher risk of developing keratinocyte cancer compared to non-exposed workers (9, 10).

Sun safety at work can be improved by the use of sun protection such as: avoiding the sun during midday, sunscreen, long sleeved shirt and trousers and a wide brimmed hat (11). In 2019, The Danish Working Environment Authority issued a news item recommending the use of sun protection at work, which in 2021 became a requirement to make sunscreen available in outdoor workplaces (12). The primary recommendation was issued one year after the publication of a survey study that showed limited awareness of occupational skin cancer risk, perceived importance and use of sun protection at work in Danish outdoor workers (13). It is unclear if these recommendations and requirements have had any impact.

Several sun safety campaigns have tried to encourage more and better use of sun protection in the general population (14). However, studies have shown that sun safety campaigns only have a short term effect, unless they are repeated and supplemented with education, policy, and environmental strategies (15). A German study showed that a 16-year period of repeated sun safety campaigns reduced the amount of sun burns in the general population from 25.9 to 17.5% (14).

Some studies have researched the effect of workplace sun protection policies and measures, but with inconclusive results (16, 17). This includes workplace education and knowledge about skin cancer, both of which have showed mixed results (16). In a study of Australian outdoor workers, education combined with skin examination to modify health risk behavior and reduce skin cancer risk was found to improve sun protection behavior (18). Attitude towards sun protection is also believed to affect sun protection behavior. In a systematic review from 2012, including 16 multicomponent intervention studies, 13 studies found a positively increased sun protection behavior, and eight studies measured a change in attitude towards skin cancer, of which only one study found a positive short time effect in outdoor workers (19).

The best way to improve sun protection behavior at work is probably by multicomponent intervention including sun safety policy, structural changes, education, skin examination, and role models (20, 21). This was shown in a study among Israeli outdoor workers, using multicomponent intervention including repeated skin examination, education, clinical training, and availability of personal sun protection gear, with consequent significantly improved sun protection behavior at work. A high proportion (80%) of the Israeli outdoor workers sustained this behavior one year after the intervention (20). The same was observed in an intervention study from Queensland, where the use of multicomponent intervention including sun safety policy at work, structural and environment changes towards sun protection, personal protective equipment, education and awareness, role modeling and skin examination led to increased use of sun protection in outdoor workers (21).

Previous studies indicate that single-component interventions are not enough to change sun protection behavior in outdoor workers. The effects of multicomponent intervention on sun protection behavior have not previously been studied in Danish outdoor workers. The aim of this study was to evaluate the sun protection behavior of Danish outdoor workers as a four-year after their participation in a PhD project that included multicomponent intervention, and one year after a recommendation on the use of sun protection at work by the Danish Working Environment Authority.

METHOD

A follow-up study of changes in the sun protection behavior of Danish outdoor workers after a four-year period and multiple interventions aimed to prevent exposure to ultraviolet radiation and the development of skin cancer, as part of the PhD project *"Solar ultraviolet radiation exposure, sun protection behavior and skin photodamage in Danish Workers"* (5). Recruitment was originally carried out in 2016/17 by means of convenience sampling among a large number of Danish companies, municipalities and unions. Participants had to be active in the labor market (inclusion criteria) and could not have insufficient Danish language skills (exclusion criteria, 13). In 2016/17, 499 participants completed the PhD study questionnaire including items on demographic characteristics, occupational history, awareness of skin cancer risk and use of sun protection at work, at leisure, and on sun holiday (13). In 2020, the same participants were contacted by email. In case of no response, they received a text-message or a telephone call and asked to complete a shortened follow-up version of the PhD study questionnaire, including the exact same items in terms of awareness of occupational skin cancer risk, perceived importance and use of sun protection at work (13) (**Supplementary Material**). The PhD study questionnaire included 47 items, of which 33 were reused in the follow-up study questionnaire. Most of the items were new constructs developed particular for the PhD study. Before use, three experienced researchers reviewed and six representative workers completed and evaluated the PhD study questionnaire to improve its face validity (13). Between survey interventions included: two-weeks personal ultraviolet radiation dosimetry between May 2016 and May 2017, a skin examination for signs

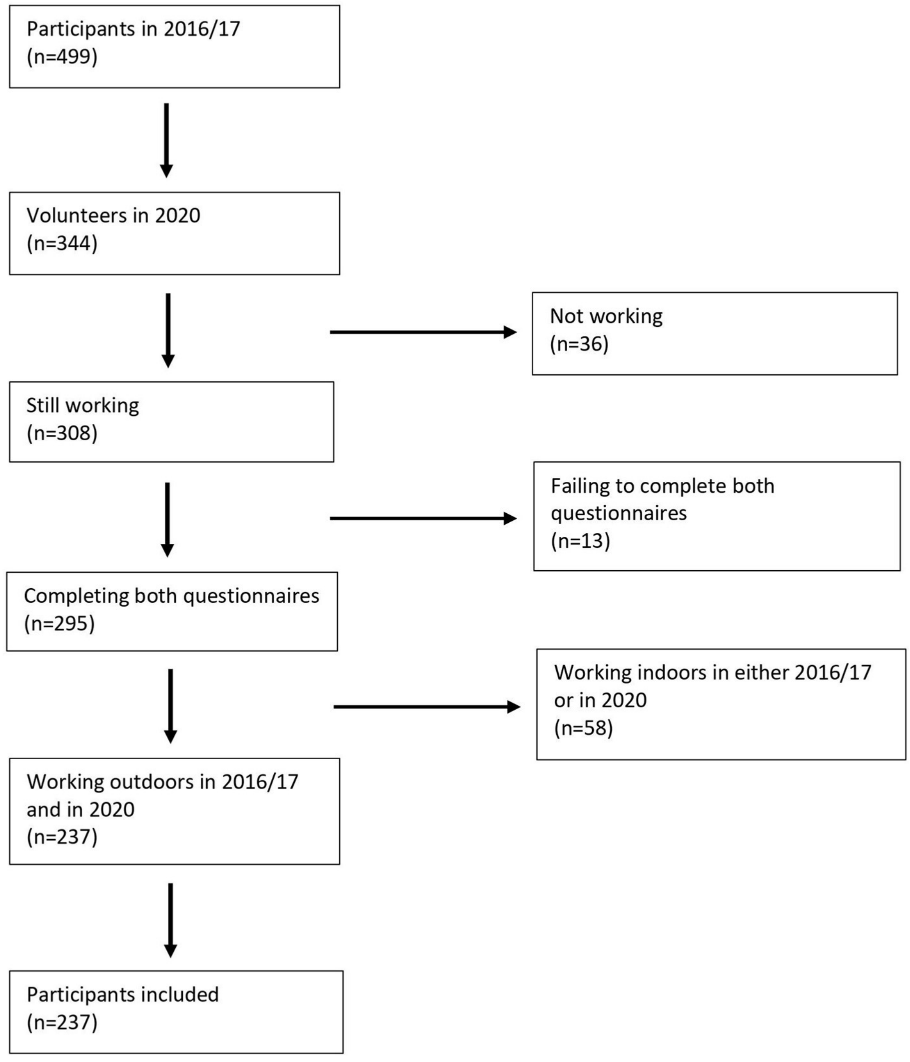

FIGURE 1 | Flowchart.

of photodamage and skin cancer in late 2016, and one-time written feedback to participants on personal exposure to solar ultraviolet radiation, skin cancer risk and recommendations on the use of sun protection in 2017 (5). None of the interventions were linked to the Danish Working Environment Authority recommendations regarding the use of sun protection at work. In this study, multicomponent intervention is defined as an intervention with at least two components.

In this study, participants that predominantly work outside or work equal parts outdoor and indoor were categorized as outdoor workers. This choice was based on results from a recent Danish dosimetry study which showed that workers who work outdoors half the time are exposed above the International Commission on Non-Ionizing Radiation Protection threshold value for ultraviolet radiation exposure of 1.0–1.3 SED per 8-hour work period (6). Also, for each outdoor worker, as a measurement of overall use of sun protection, a composite score (0–12 points) was calculated based on their answer (never = 0, rarely = 1, often = 2, always = 3) for each of the four sun protection items (avoid sun during midday, long trouser and sleeves, wide brimmed hat and sunscreen).

Statistical Analysis

McNemar's test was used to test for differences in awareness of occupational skin cancer risk as well as perceived importance, availability and use of sun protection at work between 2016/17 and 2020. Chi2- and *t*-test with standard deviation and p-values were used as statistics. All participants in the analysis completed the survey in both 2016/17 and in 2020. We did a further analysis to assess if statistically significant changes in the use of sun protection at work were related to skin examination, awareness of occupational skin cancer risk, or perceived importance and availability of sun protection at work. Sensitivity analyzes were done for participants with multicomponent intervention.

Multiple variate regression was done to assess the influence of demographic variables on change in composite score. Statistical significance was determined using $\alpha = 0.01$. The JMP 14 statistics program was used.

RESULTS

Of the original 499 participants, 344 agreed to complete the follow-up study questionnaire. Hereof, 308 were still working. Of these, ten did not sufficiently complete the original PhD study questionnaire and three did not complete the follow-up study questionnaire. Of the remaining 295 volunteers, 58 were excluded since they were working indoor either in 2016/17 or in 2020, resulting in a final tally of 237 outdoor workers without job changes completing both study questionnaires, as participants in this study. **Figure 1** shows the process in a flowchart.

Table 1 shows the baseline characteristics of the participants based on their responses in the original and in the follow-up study questionnaire. Most participants were men (77%) with a mean age of 45.3 years in 2016/17. The main part of participants had elementary and vocational school as their highest level of education (68%). The profession with most participants was gardener, followed by carpenter, roofer, postal worker, dockworker, road workers and others. Most had skin type 3, no history of skin cancer, never been smokers and drank/consumed less than 10 units of alcohol a week. All participants received information and education on skin cancer risk and use of sun protection and all but six participants performed personal dosimetry. About half of the participants ($n = 129$) had a skin examination done for signs of photodamage and skin cancer. In total, 231 (97%) of all participants had multicomponent intervention.

Table 2 compares the participants' answers in the PhD study questionnaire and the follow-up study questionnaire as to awareness of occupational skin cancer risk, perceived importance, availability and use of sun protection at work. The table shows that awareness of occupational skin cancer risk has changed significantly ($p < 0.001$) towards a higher incidence of moderate-high awareness of occupational skin cancer risk in 2020 (63%) compared to in 2016/17 (43%). Perceived importance of sun protection at work has similarly changed significantly ($p < 0.001$) towards a higher incidence of moderate-high perceived importance of sun protection at work in 2016/17 (69%) compared to 2020 (83%).

With regard to availability of sun protection in the workplace, a significant difference was found for the use of sunscreen ($p < 0.001$) and avoiding the sun during midday ($p = 0.002$) at work between 2016/17 and 2020. As to the use of sun protection at work, a significant increase in composite score ($p < 0.001$) was shown between 2016/17 and 2020. More importantly, a significant difference was found in the use of sunscreen ($p < 0.001$), avoiding sun during midday ($p = 0.002$) and wearing a wide-brimmed hat ($p = 0.008$) at work between 2016/17 and 2020. Hereof, the percentage change was by far the largest for sunscreen at work, used often or always by 37% in 2016/17 and by 52% in 2020.

TABLE 1 | Baseline characteristics of the participants.

	Responses	Results ($N = 237$)
Sex[a]	Male	183 (77%)
	Women	54 (23%)
Age[a]	Mean (Std. Dev)	45.3 (10.3)
Educational level[a]	Elementary or vocational school	161 (68%)
	High school	19 (8%)
	Higher education	46 (19%)
	Other	11 (5%)
Profession[a]	Gardener	58 (24%)
	Carpenter	20 (8%)
	Roofer	22 (9%)
	Postal worker	17 (7%)
	Dock worker	15 (6%)
	Road worker	12 (5%)
	Others[f]	93 (41%)
Skin type[a,d]	Type 1	5 (2%)
	Type 2	61 (26%)
	Type 3	103 (43%)
	Type 4	56 (24%)
	Type 5	12 (5%)
Personal history of skin or lip cancer[b]	Yes	12 (5%)
	No	225 (95%)
Smoking[b]	Never	168 (71%)
	Former	28 (12%)
	Current	41 (17%)
Alcohol[b]	Never	45 (19%)
	Less than 10units/w	166 (70%)
	More than 10units/w	26 (11%)
Skin examination[c]	Yes	129 (54%)
	No	108 (46%)
Dosimetry[e]	Yes	231 (97%)
	No	6 (3%)
Employed in same job[b]	Yes	206 (87%)
	No	31 (13%)
Working outdoor or equal indoor/outdoor[b]	Outdoor	187 (79%)
	Equal indoor/ outdoor	50 (21%)

[a]*Results from 2016/17.*
[b]*Results from 2020.*
[c]*In study late 2016.*
[d]*According to the Fitzpatrick scale (25).*
[e]*In study between May 2016 and May 2017.*
[f]*Concrete technician, surveyor, machine operator/driver, mason, porter, renovation worker, scaffolding worker, road worker, sewer construction worker, mason, various outdoor workers.*

TABLE 2 | Comparison of the participants' awareness of sun safety, availability of sun protection, and use of sun protection at work in 2016/17 and 2020, respectively.

		2016/17	2020	Chi²/ t-test	*p*
	Awareness of sun safety at work (*N* = 237)				
Awareness of occupational skin cancer risk	Not considering	110 (46%)	71 (30%)	35.87	<0.001
	No or low	26 (11%)	16 (7%)		
	Moderate	56 (24%)	88 (37%)		
	High	45 (19%)	62 (26%)		
Perceived importance of sun protection at work	No	27 (11%)	9 (4%)	29.74	<0.001
	Low	47 (20%)	30 (13%)		
	Moderate	88 (37%)	103 (43%)		
	High	75 (32%)	95 (40%)		
	Workplace availability of sun protection (*N* = 237)				
Avoid the sun during midday	Yes	14 (6%)	30 (13%)	9.85	0.002
	No	223 (94%)	207 (87%)		
Long trouser and sleeves	Yes	219 (92%)	204 (86%)	10.76	0.013
	No	16 (7%)	33 (14%)		
	Missing	2 (1%)	-		
Wide brimmed hat	Yes	111 (47%)	129 (54%)	5.19	0.159
	No	125 (53%)	108 (46%)		
	Missing	1 (1%)	-		
Sunscreen	Yes	70 (30%)	126 (53%)	35.66	<0.001
	No	167 (70%)	111 (47%)		
	Use of sun protection at work (*N* = 235)				
Composition score	Mean [95% CI]	4.0 [3.7, 4.3]	4.6 [4.3, 4.9]	$t_{(235)} = 5.32$	<0.001
	Std. Dev	2.0	2.1		
Long trouser and long sleeves	Never	22 (9.5%)	30 (13%)	8.48	0.205
	Rare	118 (50%)	115 (49%)		
	Often	87 (37%)	73 (31%)		
	Always	8 (3.5%)	17 (7%)		
Wide brimmed hat	Never	113 (48%)	93 (40%)	17.48	0.008
	Rare	58 (25%)	64 (27%)		
	Often	37 (16%)	47 (20%)		
	Always	27 (11%)	31 (13%)		
Sunscreen	Never	51 (21%)	34 (14.5%)	33.18	<0.001
	Rare	99 (42%)	78 (33.5%)		
	Often	65 (28%)	85 (36%)		
	Always	20 (9%)	38 (16%)		
Avoid the sun during midday	Never	127 (54%)	102 (43%)	20.44	0.002
	Rare	91 (39%)	105 (45%)		
	Often	15 (6%)	25 (11%)		
	Always	2 (1%)	3 (1%)		

Analysis done for participants answering both questionnaires with a few missing values.

Sensitivity analyzes including only participants who had received multicomponent intervention did not change the significance of the results.

Table 3 shows the use of sunscreen at work in relation to skin examination, availability of sunscreen, awareness of occupational skin cancer risk and perceived importance of sun protection at work. A significant association was found between use of sunscreen at work and both awareness of occupational skin cancer risk ($p < 0.001$) and perceived importance of sun protection ($p < 0.001$) at work. By looking at the percentage differences, it seems likely that an increase towards a higher awareness of occupational skin cancer risk and perceived importance of sun protection increased the use of sunscreen at work. The table also shows that the use of sunscreen at work was not significantly related to neither skin examination nor availability of sunscreen in the workplace in 2020.

A similar analysis was made/done for avoiding the sun around midday and use of a wide brimmed hat. In this, a statistical significant association was found only between workplace availability and use of avoiding the sun around midday

TABLE 3 | Participants' use of sunscreen in relation to skin examination, workplace availability of sunscreen, awareness of occupational skin cancer risk and perceived importance of sun protection at work in 2020.

			Skin examination (*N* = 235)			
Use of sunscreen	**Yes**		**No**		**Chi²**	***p***
Never	17 (13%)		17 (16%)		2.04	0.565
Rare	39 (30%)		39 (36%)			
Often	52 (41%)		33 (31%)			
Always	20 (16%)		18 (17%)			
			Workplace availability of sunscreen (*N* = 236)			
Use of sunscreen	**Yes**		**No**		**Chi²**	***p***
Never	16 (13%)		18 (16%)		1.23	0.772
Rare	40 (32%)		38 (35%)			
Often	49 (39%)		36 (33%)			
Always	20 (16%)		18 (16%)			
			Awareness of occupational skin cancer risk (*N* = 236)			
Use of sunscreen	**Not considering**	**No or low**	**Moderate**	**High**	**Chi²**	***p***
Never	26 (37%)	4 (25%)	4 (5%)	1 (2%)	76.60	<0.001
Rare	30 (42%)	8 (50%)	28 (16%)	12 (19%)		
Often	12 (17%)	3 (19%)	40 (46%)	29 (47%)		
Always	3 (4%)	1 (6%)	14 (32%)	20 (32%)		
			Perceived importance of sun protection at work (*N* = 237)			
Use of sunscreen	**No**	**Low**	**Moderate**	**High**	**Chi²**	**p**
Never	5 (56%)	10 (33,3%)	18 (18%)	1 (1%)	91.40	<0.001
Rare	-	13 (43,3%)	46 (45%)	16 (17%)		
Often	3 (33%)	6 (20%)	34 (33%)	46 (48%)		
Always	1 (11%)	1 (3,3%)	4 (4%)	32 (34%)		

($p < 0.001$). However, the numbers were quite small with only ten outdoor workers having both availability and always or often use of avoiding the sun around midday in 2020.

In addition, to see whether the change in the composite score could be explained by differences in demographic variables in 2016, we performed a multiple linear regression with change from 2016/17–2020 in the composite score as the dependent variable and sex, age, skin type, and work and educational level as explanatory variables. The result of the multiple linear regression model showed that the observed change in composite score could not be explained by differences in the dependent variables $F_{(15,219)} = 1.27, p = 0.221$.

DISCUSSION

The results show a significant increase in the awareness of occupational skin cancer risk, perceived importance of sun protection and use of sun protection at work in Danish outdoor workers, following a four-year period, including multicomponent intervention aimed to prevent exposure to ultraviolet radiation and the development of skin cancer.

The modest increase in composite score for overall use of sun protection appears to be primarily driven by a marked increase in use of sunscreen at work. This more so than both avoiding the sun around midday and wearing a wide-brimmed hat at work. The increased use of sunscreen was, somewhat surprisingly, unrelated to the increased availability of sunscreen at work. Moreover, neither personal dosimetry nor skin examination alone lead to changes in the use of sunscreen at work. Thus, indicating a possible combined effect of personal dosimetry, skin examination as well as information on skin cancer risk and recommendations on use of sun protection to explain the increased use of sun protection, mainly sunscreen, in the workplace.

The results of this study thus seem to support the notion that the best way to improve sun protection at work, especially the use of sunscreen, in Danish outdoor workers is through the effects of multicomponent intervention. This finding is in line with international studies demonstrating the efficacy of multicomponent interventions to increase the use of sun protection at work, in particular with regard to personal protective equipment such as sunscreen (15, 22).

The marked increase in Danish outdoor workers' use of sunscreen at work may be due to it being more readily available and well known compared to other types of sun protection. Also, outdoor workers are likely to have a significantly higher impact on the use of sunscreen compared to other types of sun protection during working hours. Whatever the reason, the increased use of sunscreen by Danish outdoor workers is a step in the right direction and something to build on in terms of improving sun safety at work. That being said, sunscreen is generally considered the least effective type of sun protection and best used in combination with other more effective types of sun protection (23). It is therefore important to emphasize an additional need for sun protective clothing, and to avoid the sun around midday whenever possible during working hours.

In a recent systematic review, the immediate feedback from personal monitoring of physical activity was shown to effectively increase physical activity in a Danish adult population (24). In this study, although feedback from personal dosimetry of ultraviolet radiation was not immediate, but rather delayed by several months, the increased use of sun protection at work may, to some extent, be attributed to the use of personal dosimetry. However, it is not possible to assess such a correlation, as virtually all outdoor workers participated in this intervention. The potential of using personal dosimeters with immediate feedback to increase sun safety at work is nevertheless an interesting research question that should be investigated further.

The main strength of this study is the use of repeated measures in that the same cohort of outdoor workers were being measured using the same dependent variables with 3–4 years' intervals. Also, the inclusion of a broad selection of professions representing outdoor workers allow for a reasonably wide generalization of results. Although not all participants were subject to multicomponent intervention, complete and unbiased knowledge of single-component interventions for each participant allowed for a detailed and reliable analysis.

The study is limited in terms of investigating a possible confounding effect of the recommendations by the Danish Working Environment Authority regarding the use of sun protection at work by a lack of data. The fact that skin cancer risk perception as well as the use of sun protective measures both increase with age, and the risk that some participants may have engaged in other potential confounding measures, i.e. a second skin examination between surveys, are also potential confounders. The PhD study questionnaire was evaluated only with respect to face-validity and no other important psychometric properties such as reliability and norming or sensitivity to change. Additionally, self-evaluated use of sun protection may lead to over- or underestimation, although this is likely to remain the same for each participant over a four-year period and thus not significantly affect comparisons in this study. Moreover, as in the original study, selection bias and consequent low generalization of results cannot be ruled out. Besides, the use of composite scores may lead to skewed results. Also, the composite score assigns the same weight to each component, suggesting that each is equally effective as sun protection, which has been taken into account in the analysis and discussed in more detail. Lastly, the study is limited by not having a control group and as such, this is not an intervention study.

CONCLUSION

Based on the findings in this study, it seems possible to influence the awareness of occupational skin cancer risk and use of sun protection in Danish outdoor workers positively during working hours by multicomponent intervention. Clearly, the greatest effect is seen/observed for the use of sunscreen. However, when it comes to sun protective clothing and avoiding the sun around midday, a higher degree of involvement from the employer in terms of workplace policy and equipment availability and/as well as from the Danish Working Environment Authority in terms of rules and regulations for sun protection at work is needed.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical approval was not provided for this study on human participants because this is in accordance with recommendations by The Zealand Ethical Scientific Committee and Data Monitoring Authority. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

KG and OM planned the project. MJ and KG acted as main co-authors. MJ carried out the statistical data analysis. OM supervised the work. All authors has contributed in the final version of the paper.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.885950/full#supplementary-material

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Assessing Human Eye Exposure to UV Light: A Narrative Review

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Exposure to ultraviolet light is associated with several ocular pathologies. Understanding exposure levels and factors is therefore important from a medical and prevention perspective. A review of the current literature on ocular exposure to ultraviolet light is conducted in this study. It has been shown that ambient irradiance is not a good indicator of effective exposure and current tools for estimating dermal exposure have limitations for the ocular region. To address this, three methods have been developed: the use of anthropomorphic manikins, measurements through wearable sensors and numerical simulations. The specific objective, limitations, and results obtained for the three different methods are discussed.

Keywords: ocular exposure, ultraviolet radiation, UV, eye, ocular dosimetry

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1. INTRODUCTION

The obvious increase in environmental ultraviolet radiation (especially the range of UVB, 280–315 nm, and UVA, 315–400 nm) that we have been witnessing for some years has also aroused interest the fields of ophthalmology and optometry (1). Adverse effects could result from excessive exposure in this wavelength range, and several studies have found that a variety of diseases occur from excessively high values of energy absorbed in the ultraviolet range by ocular tissues (1). Of course, artificial UV light is not exempt from this negative effect on human health (2).

The ambient irradiance conditions are determinant in the ocular exposure, but the relationship between the ambient UV intensity and the intensity of light received in the eye is unfortunately not straightforward. The eye is a spherical (aspherical or bi-spherical) and obstructed surface, oriented (most of the time) vertically. Previous studies have indeed shown that ambient irradiance, often represented by the UV index (UVI), is an inadequate predictor of the ultraviolet radiation exposure of eye (3).

The UV index, according to the World Health Organization (WHO), is identified by a number representing the level of UV radiation, therefore the possible risk of developing sunburn or sun erythema of the skin, more or less severe, during a certain exposure time. The UV index is expressed as a function of time and location, so much so that it has become a forecast of risk scenarios for the public. It is determined from a measure (or estimate) of the amount of environmental irradiance by weighting the UV frequency spectrum according to the sensitivity of the human skin (erythemal spectrum) (4). It is clear that this index is not developed to ascertain (or predict) a possible harmful scenario for the eye in an arbitrary external situation.

Previous studies evidenced that a situation that is not risky in terms of adverse effects to the skin (such as sunburns) could still be risky for the eyes.

In addition to the biophysical reason, i.e., that the UV index refers to the skin sensitivity and not eye sensitivity, there is also a second reason, of a geometrical nature explaining why ambient irradiance is a poor indicator of eye exposure. In the vast majority of cases, the UV index is calculated from the irradiance spectrum measured on the surface of the earth (5), which is not representative of the anatomical zones of the human body, especially the orientation (mainly vertical) and geometry of the eye.

In this regard, Hatsusaka et al. (3) define an ocular UV index (OUVI), i.e., a specific UV index for eyes. Through measurements, obtained with an anthropomorphic manikin, Hatsusaka et al. relate the environmental irradiance with the ocular irradiance and defines, by means of a simple linear regression, a formula that allows to calculate OUVI (using the same scale of the UVI) directly from the ocular UV irradiance. Comparing the UVI and the OUVI, the same index was noted around midday in summer, whereas in the morning and the afternoon a higher level of OUVI is registered (an average value of 3.7 vs. 2.5). During the winter, when UVI values are generally low (maximum index of 1), the OUVI instead records values up to 4.

A number of parameters must be considered to understand eye exposure: how much light it receives, how it is distributed over the ocular surface and how the eye changes as a function of environmental conditions. These are generally assessed by direct or indirect measurements of the ocular dose received. Measuring the ultraviolet radiation (UVR) eye dose is a significant challenge as it depends on several factors that are not always easily measurable or repeatable in experiments, and above all cannot be parameterized using empirical formulas. It is necessary to consider that this value has, above all, a great anatomical-geometric dependence [as has already been investigated in numerous works, such as that of Sliney (6, 7)]: the surface of the eye is indeed an obstructed surface which has a sensitive part whose surface changes continuously.

Physiological phenomena such as squinting and different blink frequencies impose, moment by moment, a variation of the sensitive surface exposed to light. Recently, the filtering role of the eyelashes and how they can reduce the intensity of ultraviolet light received by the eye depending on the direction of the incoming light has been investigated (8). Furthermore, the rotation of the eyeball have also obvious repercussions on the amount of radiation received inside the eye (9). The rotation of the head imposes a further degree of complexity to the phenomenon, as there is no particular pattern followed but always a series of random directions that change moment to moment. Environmental factors [as pointed out in (10, 11)], such as the amount of reflected light, which in turn depends on the local albedo conditions, influence the determination of the effective exposure. Although there are no specific studies on this subject to the author's knowledge, it is generally hypothesized that eyebrows reduce the intensity of light reaching the eye, especially for sufficiently large angles of the sun's elevation. The possible role of hair cannot be ruled out either. Experimental studies have shown that hair acts as a protective agent against UV radiation (12, 13).

The aim of this paper is to provide a narrative review based on the research question: *how does ultraviolet light reach our eyes?* This question is addressed through a narrative review, aiming at understand and study all the variables affecting this exposure. This research focuses on works found in the literature that aim to measure the ocular exposure to ultraviolet light and study the influence of the environmental and anatomic exposure determinant. Both ambient and artificial sources of UV light were included, although the latter are limited. The study of the relationship between the level of environmental UV and ocular exposure, also excluding studies that specifically investigate the effect of UV radiation absorption on ocular tissues, is generally complex and difficult to determine. The variables that influence this measure are in general greater in number than in a laboratory-controlled case. The research question is therefore oriented to understand the factors that determine ocular exposure and the different methods adopted to study these factors.

2. METHODOLOGY

There are many variables involved in these measurements, as described in the previous section. However, the method used allows the study to focus on specific variables. It imposes certain restrictions on the variable to be investigated, therefore a grouping that was quite efficient was by method.

The research strategy followed in producing this article is that of a narrative review. Eligibility criteria were defined such that articles related to UV light that specifically addressed the human eye or ocular region were included. Consequently, articles that did not treat UV light and that did not focus on the human eye were excluded.

The articles were first selected by title. Abstracts and conclusions were read for the selected articles, leading to a second selection. Finally, the complete reading of the articles led to the creation of a final set. The literature cited by the selected articles was analyzed with the aim of finding other articles related to the research question. In addition, some articles were selected since they were considered relevant as examples and to show further methods and application. The entire research, analysis, reading and selection of articles was carried out by a single person. The databases used for this research were: *Web of Science*, *Google Scholar*, *PubMed*, and *IEEE Xplore*. The keywords used were *(radiation) ocular exposure*, *ocular irradiance*, *ocular ultraviolet radiation*, *eye (ultraviolet) exposure*.

The process followed in this research strategy is schematized in **Figure 1** as flow diagram.

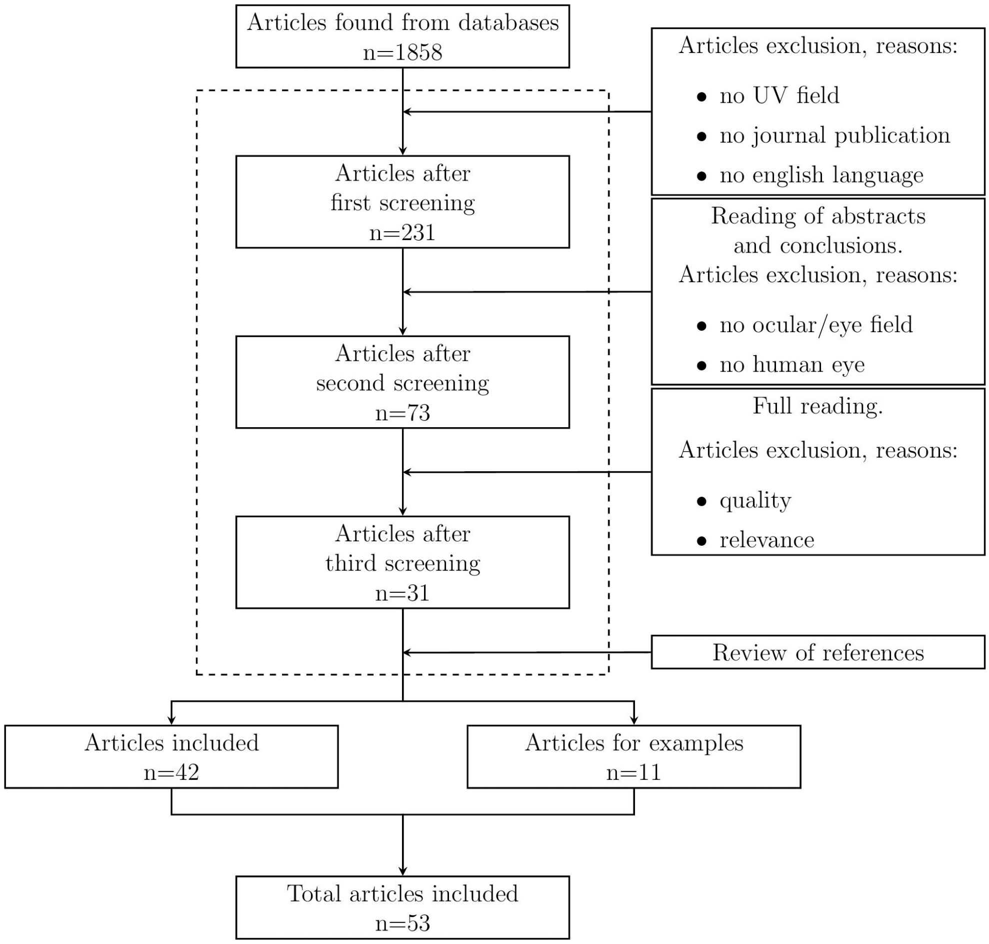

FIGURE 1 | Flow diagram of the review process performed in this review.

3. MEASURING OCULAR EXPOSURE WITH ANTHROPOMORPHIC MANIKINS

A fairly widely used method to determine the amount of light reaching the ocular area, as well as the distribution of light as a function of daily parameters such as the angle of elevation of the sun, is through the use of anthropomorphic manikins [such as in (14–18)]. The experimental setup is almost always the same and consists of using a light sensor inserted into the eye area of the manikin and then exposing the manikin to sunlight for an arbitrary period of time. This measurement does not represent the amount of light arriving on the cornea (which would undoubtedly be more interesting), but the light arriving on the ocular area. This is because a light sensor is generally a flat surface, which does not represents the aspherical (or bi-spherical) surface of the human cornea. Typically, the surface of the sensor coincides with the apex of the cornea, so that the surface is tangent to it.

The anatomy of the manikin plays an important role in this method, since different manikins' morphologies will cast different shadows for different solar elevation angles. This was evidenced by the work of Chen et al. (19) in which two mannequins with typical average facial features of Asians and Europeans demonstrate a different level of ocular exposure caused by the difference in superciliary arch and glabella. However, this is also true for a human population: inter-individual variations in anatomy will undoubtedly influence the results. The position of the light sensor could also influences the final result (although it is sometimes not reported as a decisive factor). Indeed, considering possible variations for the optical axis alone, in a hypothetical situation where the sensor is partially covered by a shadow cast by a part of the face (e.g., the nose) at a relatively large angle to the normal of the sensor surface, this variation could lead to considerable differences in the results. The same concept also applies to variations in position in the plane normal to this axis. These two sources of error make the results found in the different works difficult to compare (whether a comparison should be necessary or not). However, given the relative ease of the experiment, as well as the similarity of the facial anatomy profile, it is possible to find a common trend in the results. It is interesting to note, however, that none of the studies identified with manikins mentions the issue of light reflection as a geometric factor that could affect the final result, for example by altering the reflectance value (20).

The method of manikins used to measure ocular radiation has some rather obvious limitations. First, it does not record a typical daily ocular exposure to light, which is certainly much more complex to determine, but the result in relation to the angle of the head and the height of the sun above the horizon. Second, it does not record the complex influence of phenomena such as squinting or change of head direction on the effective exposure. In about half of the studies reviewed, the manikin's head is orientated with a downward frontal angle (usually 10° or 15° below the horizon) to represent a realistic situation of a person who is walking. Some studies rotate the manikin by a complete tour on itself around the horizontal plane to determine the same result from all head orientation, as in (21–26). Considering, that the time of rotation on the manikin on itself is less than the time necessary for a significant variation in the displacement of the sun in the sky (and therefore also of its irradiance), this rotation allows a richer data recording for a given elevation angle of the sun. Instead, some studies point the manikin always toward the sun, as in (27).

Some studies conducted with manikin method are intended to investigate the amount of light reaching the eye and its dependence to environmental parameters as well as facial anatomy, without consideration to health or prevention issues. Predicting the effect of the solar elevation angle the resulting seasonal variation is, for instance, not straightforward. Studies with anthropomorphic manikins showed a similar pattern among different experiments, namely that of a bimodal distribution. It is usually shown during warm seasons, when the solar elevation angle becomes high enough to prevent direct radiation from the sun from hitting the eye. In this particular time interval, it can be seen that during a daily exposure, while the ambient radiation increases with the solar elevation angle, there is no increase in the received ocular radiation, but rather a decrease. Indeed, the radiation that reaches the eye (the light sensor) in this time interval is only due to the sum of the diffuse radiation and the reflected radiation from the ground surface (albedo). This profile occurs because of the superposition of two effects: the anatomy of the ocular area and the orientation of the receiving surface of the eye. The bimodal distribution was also observed for measurements that did not directly target the eye, but other parts of the head, in particular the cheeks and the nose, thus vertically oriented surfaces. For example, in Wang et al. (25, 28) the ambient irradiance is measured on various parts of the face using a manikin. Bimodal distribution was observed for sensors located on the cheeks, nose tip and forehead, indicating that the orientation of these surfaces plays a key role in determining the risk factor. The profile of the bimodal distribution changes throughout the year. Generally, it is not observed in the cold season, as the sun does not reach sufficiently high elevation angles.

In other words, at equal intensity we receive more direct light during the months (or in locations) where the sun does not reach high elevation angles. The discussion becomes more complicated if we consider that the intensity of ambient UV light changes throughout the year and generally reaches its maximum value in summer. Sasaki et al. (29) compared the total exposure received by the eye area of a manikin exposed on 21 September and then on 21 November, both times facing the sun. The daily UV intensity in September was only 8% higher than in winter despite an almost 30% decrease in daily ambient UV intensity. Daily eye exposure during the solstices and equinoxes were also recorded by (23). Bimodal distribution was observed for autumn, spring, and summer. Notably, for the latter season, ultraviolet exposure values were higher in the morning and evening, rather than around midday, when the ambient UV intensity is at its highest. Furthermore, the highest daily ocular exposure value recorded appears to be in winter.

The manikin method was also used to determine the level of UVR received by the ocular region in an indoor situation by varying the orientation and distance of the manikin in a room relative to a window (30).

Anthropomorphic manikins have also been used to study the level of protection offered by objects developed for this very purpose, such as sunglasses and hats, as in (31). This is also the case in (32), in which two manikins (heads) on which UV sensors have been placed are used to determine the level of protection offered by a hat. Meanwhile, in (33), a manikin is used to measure UV exposure in sitting and standing positions.

4. MEASURING OCULAR EXPOSURE WITH WEARABLE SENSORS

Another method used to measure ocular exposure is to fit light sensor and then exposing the carrier in a given scenario. In this regard, Fleming et al. (34) developed a particular device consisting of five UV sensors. This apparatus was mounted on a spherical plastic shell of a size that could be superimposed on the eye (with the eyelids lowered). Wearable sensors are always used for preventive purposes, aiming at establishing the amount of UV rays received by the front ocular surface for different solar elevation angles. In this case, these five sensors together, which cover the eye from the nasal to the temporal-central area of the eye, have a greater field of view than a flat-sensing-part single sensor. This feature makes this method versatile, as it can measure the UV radiation in different areas of the ocular region and record, for example, the UV absorbed by the nasal limbus. Similarly to the manikin method, it involves measuring ultraviolet radiation using different head orientations. The sensor is, however, not used in situations where the subject can move, which brings to this method the limitations already seen for the manikin method. The same method was previously used by (20) to investigate the influence of ultraviolet radiation reflected by the skin of the nose. In this case, the experiment was carried out under controlled lighting conditions by using a diffuse artificial light source to illuminate the five sensors. Walsh observed an increase in UVR on the nasal side of the eye due to light reflection of the nose.

A similar method, but with an even more ambitious goal, is to measure ultraviolet radiation directly on the surface of the eye. This solution, presented by Sydenham et al. (35), uses polysulphone contact lenses, which degrade when exposed to ultraviolet radiation. This material had already been widely used for dosimetric measurements, but never in the form of contact lenses. Knowing the dose-response between UV light and polysulphone lenses degradation, it is possible to quantify exposure by comparing the absorption of the lens before and after exposure by spectrophotometry. Because of the material of which these lenses are made, the measurement time was limited to a maximum of one hour, although it is feasible to extend this time with specific adapters. The results, expressed in terms of Ocular Ambient Exposure Ratio (OAER), are compatible with measurements found in previous works. The same method was used McLaren et al. (36) (of which Sydenham is in fact a co-author). In this study the contact-lens method was applied to measure the ocular UV dose received by two subjects during a winter day. Differences were found between McLaren et al.'s and Sydehham et al.'s results, but these were attributed to differences in the experimental setup.

Unfortunately, no recent studies have been found on dosimetric measurement using contact lenses specifically for UV radiation. Instead, this method is currently used, with some refinement and improvement, in the field of diagnostic radiology, thus using ionizing radiation. In this respect, we cite, as an example, the work of Park et al. (37) in which contact lenses made of acrylic material were developed for *in vivo* measurements of the dose received during radiotherapy sessions. Similarly, Kim et al. (38) proposed contact lenses for *in vivo* dosimeter measurements in the field of radiation therapy. Compared to the anthropomorphic manikin method, the main advantage of the contact-lens method is more realistic dose measurement, theoretically closer to the true exposure value. This is because contact lenses do not need a flat measurement surface, as do light sensor, nor do they have the same sources of error with regard to positioning (although for contact lenses it becomes important to quantify lens rotation during the measurement period). The contact-lens method could also be assumed to reflect better the effective ocular dose received by an individual since it take into account dynamic effects, such as eyes and eyelids movements. When using manikins, one determines the dose received by the eyes in a given static situation, which do not vary during the measurement. While the manikins can often rotate horizontally, which makes for interesting measurements, the final result is still far from a true exposure received by a human eye. Contact lenses allow researchers to quantify the ocular exposure to light in a typical outdoor situation, enriching the final data with all those processes that are difficult to quantify or emulate in manikin, such as squinting, change of head direction, and blinking.

Some studies propose alternative methods to both the manikin or contact lenses, for example Duncan et al. (39–41). These studies combine the measurement of the eye dose by means of a light sensor and a mathematical model for the determination of the level of exposure received during a certain time period. Similarly to Sydenham et al., it is based on the concept of the OAER, defined as follows

$$R_{oa} = E\left\{\frac{\int f_T(t)E_a(t)dt}{\int (f_T(t)/f(t))E_a(t)dt}\right\}. \quad (1)$$

Where E is the expectation operator, $E_a(t)$ is the global environmental exposure ratio, $f(t)$ is the fraction of global environmental exposure that hits the plane tangent to the apex of the cornea and $f_T(t)$ is the time spent outside, which is 0 in the case where no exposure occurs. The OAER is calculated from measurements taken using light sensors (some developed for this purpose) worn by a population of individuals, which record UV (and visible) radiation in the tangent plane to the face and ambient UV (and visible) radiation. This quantity makes possible to determine the personal exposure from the estimated exposure according to the formula:

$$H_p = NR_{oa}\left[\sum_i F_t(t_i)Q_a(t_i)\right]T_{hat}T_{eye}G. \quad (2)$$

Where N is the number of days, $F_t(t_i)$ is the average fraction of time spent outside for the time interval t, $Q_a(t_i)$ is the average environmental exposure during the same time interval, T_{hat} and T_{eye} are correction factors that take into account the presence or absence of hats and glasses, respectively, and G is the geographical correction factor, which takes into account ozone and cloud cover (measured by satellites). The type of measurement performed and the sensor used may constitute limitations of this method, as it does not measure the UV radiation arriving on the eye surface or take into account blinking, squinting and light reduction due to eyelashes and eyebrows. Other types of limitations, however, were resolved using interviews, such as for the quantification of time spent wearing hats and glasses (terms T_{hat} and T_{eye} in the Equation 2). This method undoubtedly has advantages over other methods that used solely interviews, without any kind of measurement, as in (42), where UVR exposure is estimated from man-made (welding) sources, using a simple three-index system (numbers of workers exposed, time of exposure, and intensity of exposure).

In this regard, a number of works on the investigation of ocular exposition of welders were carried out, even though the measurements do not focus directly to the eye (43). The methods already reported in this section (e.g., using often polysulphone films) were used in this filed for determining the dose received from this artificial source.

A concept similar to Duncan's method involving the use of questionnaires and a mathematical model based on the OAER, but without corrective parameters, was also applied to a population study in (44). A slightly different formulation was described and used instead in (45) in which now Equation (2) is used for a longer period of time by taking into account the monthly variability of the geometric correction term and the OAER, and the daily variability of all other terms. Such method was used to determine the ambient UV ocular exposure for a population in order to study the relation between UVB and lens opacities.

Approaches which are similar but do not implement a mathematical model, have been used to assess exposure to other parts of the body. In (46), a sensor was used to determine exposure for several subjects during their usual activities (children, lifeguards, and mountain guides). In (47), a sensor placed vertically and attached laterally to the head was used to record the UV exposure of mountain guides over a period of one year.

5. ESTIMATING OCULAR EXPOSURE WITH NUMERICAL SIMULATIONS

A distinction must be made among the different types of numerical models used to determine the radiation dose received by the eye. There are two main types, and each has different purposes and applications.

- Tissues dosimetry models
  The most widely used models simulate ionizing radiation, i.e., short-wave radiation (mainly X-rays and gamma rays) that according to ISO standards conventionally also cover part of the ultraviolet range, specifically the part of this range where the wavelengths are shorter. These models, which are also probably the most used, are mainly used for medical applications, to determine by numerical simulation the dose to the eye (or some specific part of it) during a radiotherapy (or similar) session. Such models typically use Monte Carlo simulation techniques to simulate the path of many photons and their interaction with matter. For example, in Carinou et al. (48) numerical Monte Carlo simulations are performed to emulate radiology and cardiology sessions using virtual manikins. In Caracappa et al. (49), a detailed multi-resolution eye model was developed and then inserted into a virtual manikin to simulate the dose received from a source between 10^{-2} and 10 MeV. In a more recent paper, Santos et al. (50) implemented a multi-resolution model to determine the best solution for an eye dosimetry model. The number of studies dealing with ocular dosimetry simulation of ionizing radiation is substantial. We will not detail them further here, as it is beyond the scope of this review.
- Surface models
  In contrast to the tissues dosimetry models, these models simulate light exposure at the body surface, involving macroscopic variables, such as irradiance and radiant dose. They do not consider either individual photons or their interaction with matter, but only the dose absorbed by a single surface, more or less complex.

In the case of the tissue dosimetry models, the simulation emulates an indoor laboratory situation while typically in surface models an outdoor situation is analyzed and subjected to illumination by ambient UV radiation. These outdoor setting also differs in its spatial distribution. Furthermore, for tissues dosimetry models the simulation is usually static, i.e., the parts subjected to the treatment with ionizing rays are fixed during the simulation time. For surface models this aspect is not always present, since the aim is to best represent a dynamic situation, where the body position will change during the simulation period. For this reason, surface models concentrate on the simulation of cumulative variables, such as the radiant dose, expressed as a function of periods of many hours (or days or even more) of exposure, unlike the tissues dosimetry models. The behavior of the surface models approximately emulates approximately the situations described above with manikins and light sensors. Surface models have been developed and used to numerically estimate the exposure to natural ultraviolet light for different situations. In general, there are no models developed specifically for ocular exposure, but models to determine skin exposure. In many cases, numerical models that simulate light exposure of the skin are in some way usable or adaptable to simulation for ocular exposure, so they will be reported here when deemed adaptable to the ocular exposure. Perhaps, the greatest challenge of these numerical models has been to find a way to parameterize the complex outer surface of a person, since they are intended to simulate the radiation received by different parts (anatomical zones) of the human body. A typical research question answered by these simulations is *how does the total radiation received for a given period of time is distributed over the whole body?*

A versatile solution to this problem of parameterizing the surface of the human body was presented by Streicher et al. (51). In this study, the complex geometry of the problem is represented by a set of flat triangles, arranged in space and oriented to approximate the real surface. Together with this three-dimensional object, it is possible to simulate the path of the sun during an arbitrary period of time and, by means of ray-tracing techniques, to calculate the portion of energy received by each triangle. The model also takes into account the diffuse component of the sunlight (which is mandatory for simulations of this type), and calculates the sky view factor for each triangle, without taking into account ground reflection, thus assigning an albedo value of 0. The results are presented for 20 different anatomical zones of the human body, obtained by averaging over defined sets of triangles that compose the various zones.

The same methodology was used by Vernez et al. (52), who present a numerical model (SimUVEx, from Simulation of solar UltraViolet Exposure) able to use real solar irradiance data to simulate the exposure received on the skin. Here too, the surface of the human body is represented by a set of triangles, described as coordinates in space stored in a single text file. This model also takes into account the radiation reflected locally from the earth's surface, modeling it as a Lambertian source. The model, which was later improved to also implement diffuse anisotropic radiation, has been used to investigate UV radiation received in various scenarios. For example, SimUVEx was used in the work of Backes et al. (53) to calculate exposure in the ocular region with various types of glasses. Subsequently, an even more updated version of SimUVEx, which features several improvements, was used in (8), specifically for the eye.

6. CONCLUSIONS AND FUTURE PERSPECTIVES

This review summarizes the current publications concerning ocular exposure to ultraviolet light. Quantifying the intensity of this radiation received by the eyes, and further how this is distributed, is a challenge that can be addressed with different methods. The methods reported in literature, along with their limitations, are highlighted in this study. Along with that their limitations, their potential and possibilities are also described, marking the particular goal and application of each method. They were grouped into three categories: the method of anthropomorphic manikins, the method of wearable sensors, and the method of numerical simulations. Each assessment method identified shed light on certain aspects of ocular exposure and their implications for health, exploring several research questions.

The manikin method makes it possible to study how and how much light is received in the ocular region in different situations of illumination and protection. However, such method cannot be used to determine the ocular exposure to ultraviolet light for a realistic exposure situation: eyeball rotation, head rotation, squinting, and blinking are some examples of phenomena that cannot be included in the measurement.

Some methods were shown to be more appropriate to mimic realistic exposures. This is the case of the contact-lens method, although the last application found is more than twenty years old. This rarity may be related to the increasing complexity of human subject studies, which tends to make simulation studies more popular. Other types of measurement focused instead on longer periods of time, at the expense of accuracy, estimating the OAER for general populations. This method could potentially be used anywhere, knowing the various factors that influence the particular geographical area and daily habits (i.e., time spent outside).

Finally, it was noted that the numerical simulations method is not widely used in this field, although it proves to be quite promising. Through numerical simulation it is in fact possible to simulate an arbitrary source of light, ambient and artificial, and study in detail how it distributes on an object of any shape. The real challenge is likely simulating a realistic situation, trying to include all the parameters that can influence the result. Regardless, the ability to construct arbitrary scenarios makes this method a potential resource for future research.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MM conducted the entire research, designed the method, performed its application, read and reviewed the articles, and wrote the original draft of the manuscript. LM performed the revision. DV contributed to the final revision and wrote the final draft of the manuscript. All authors contributed to the article and approved the submitted version.

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