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A systematic review of the health effects of occupational exposure to ultraviolet radiation

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Abstract

Introduction Given the increasing duration and intensity of occupational exposure to solar ultraviolet radiation (UVR), outdoor workers are particularly vulnerable to its adverse effects. This systematic review aimed to identify the health outcomes associated with occupational exposure to solar UVR, considering both negative and positive effects, and examining related factors such as occupational groups involved, sun protection practices, and study limitations.

Methods A systematic search was conducted in Scopus, Web of Science, and PubMed databases on 19 November 2024. Eligible studies were peer-reviewed, published in English between 2019 and 2024, and involved human participants occupationally exposed to solar UVR. The risk of bias was assessed using the Joanna Briggs Institute (JBI) Checklist for Qualitative Research. Data were synthesized descriptively.

Results A total of 16 studies involving 12,268 participants met the inclusion criteria. The most frequently reported adverse health effects included skin cancer, cataracts, and photoaging. On the other hand, moderate solar UVR exposure was associated with a reduced risk of colon and prostate cancers. Sun protection practices varied considerably among studies. Common limitations included methodological heterogeneity and potential publication bias.

Conclusion This review highlights the substantial health risks, and some potential benefits associated with occupational exposure to solar UVR. The findings support the urgent need for improved sun protection policies in occupational settings and call for more robust, quantitative research to better inform risk assessment and prevention strategies.

Keywords Occupational exposure, UVR, Occupational health, Skin cancer, Sun protection

1 Introduction

Exposure to solar UVR is an unavoidable reality for many outdoor workers, being both a source of health benefits and a significant risk. On the one hand, controlled UVR exposure is essential for vitamin D synthesis, which is crucial for bone and immune health, and offers protective effects against some cancers, autoimmune diseases, cardiovascular conditions, and even the treatment of diseases such as vitiligo, psoriasis, and jaundice [1, 4, 29, 34, 88]. On the other hand, excessive exposure is associated with direct and indirect health consequences, including skin carcinomas, premature skin ageing, pterygium, cataracts, immunosuppression, among others [1, 5, 29, 45]. UVR is considered the most significant risk factor for the development of basal cell carcinoma, a type of non-melanoma skin cancer [7].

Outdoor workers are particularly more vulnerable to the adverse effects of UVR due to the increased duration and intensity of occupational exposure. It is estimated that they are exposed to UV levels three to nine times higher than those of indoor workers, depending on the activity, geographical location, and protective measures adopted [45]. The new cases of skin cancer resulting from solar UVR exposure have a substantial financial impact on workers and healthcare systems [47].

Despite UVR's crucial role in vitamin D synthesis, excessive exposure has negative impacts that extend beyond the skin [2, 22, 88]. The development of cataracts, characterised by the clouding of the eye's lens or transparent membrane that obstructs light entry and impairs vision, is strongly associated with UVR exposure [2, 22, 88]. This radiation is one of the main occupational risks for outdoor workers, including farmers, fishermen, construction workers, and lifeguards [20, 80, 90]. The World Health Organization (WHO) classifies solar ultraviolet radiation (UVR) as a Group 1 carcinogen, indicating sufficient evidence of carcinogenicity in humans [35].

Environmental, individual, and occupational factors directly influence solar UVR exposure [79]. The intensity of solar UVR varies with atmospheric composition, solar angle (depending on time, season, and latitude), altitude (increasing by 4% for every 300 m), clouds (partial blockage), and reflectance of surfaces like snow, sand, and water [16, 45, 95]. Moreover, outdoor activities, preventive behaviours (use of sunscreen, clothing, and sunglasses), and skin predisposition (Fitzpatrick phototypes, with higher risk for types I and II) influence UVR exposure [3, 44, 45, 84, 95]. In occupational settings, exposure is aggravated by reflective surfaces (e.g., water or glass), work organisation during peak hours (11 am–3 pm), and postures that increase exposure of specific body areas. Outdoor workers accumulate significant chronic exposure, making solar UVR a major occupational carcinogen [72–74], particularly in sectors like agriculture and construction, affecting millions of workers globally [3, 44, 45, 84, 95]. In this sense, linking solar UVR to skin cancer, statistical data shows a significant global health concern, with recent GLOBOCAN 2022 data showing rising incidence and mortality rates for both melanoma and non-melanoma skin cancers (NMSC). In 2022, melanoma ranked as the 17th most common cancer worldwide, with an estimated 331,722 new cases and 58,667 deaths. In contrast, NMSC ranked 5th globally, with 1,234,533 new cases and 69,416 deaths, indicating a higher disease burden despite its lower lethality per case. The highest incidence rates were observed in high-Human Development Index (HDI) countries, especially in Oceania, North America, and Europe - regions characterized by fair-skinned populations and significant exposure to ultraviolet radiation [89].

To guide this systematic review, the research question was structured using the PICO framework. Specifically, the population of interest comprises outdoor workers (P); the exposure under analysis is occupational exposure to solar ultraviolet radiation (I); comparisons are made across different occupational groups and levels of sun-protection behaviours (C); and the outcomes include the positive and negative health consequences associated with solar UVR (O). Based on this, the present systematic review aims to identify the positive and negative health consequences of occupational exposure to solar UVR in outdoor workers, and how these consequences are influenced by occupational and protective factors. Additionally, it seeks to identify the professional groups studied, sun protection, and exposure doses.

2 Materials and methods

This systematic review followed the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 statement, aiming to identify the health effects associated with occupational solar UVR exposure. This systematic review method was first introduced in 2009, initially within the health sciences. Its recognition and applicability in other scientific fields became notable, with revisions in 2015 and, more recently, in 2020 [55].

2.1 Selection and identification process

This review included studies on humans in occupational contexts of solar UVR exposure, regardless of sex and age, as the focus was on the effects of occupational exposure. Studies demonstrating a direct relationship between solar UVR exposure and specific health effects, including medical components associated with this exposure, and articles in peer-reviewed journals were also included. Conversely, reviews, conference reports, case reports, congress reports, studies on plants or animals, and studies addressing UVR exposure from non-solar sources were excluded. The search for studies identifying methods used in occupational contexts to determine solar UVR exposure was conducted on three electronic databases—Scopus, Web of Science (all databases), and PubMed—on 19 November 2024.

The search employed the keywords "ultraviolet radiation," "occupational exposure," and "health effects," combined with other synonyms. Boolean operators "AND" and "OR" were used to create the search strings, as shown in Table 1.

Articles were analysed and stored for subsequent removal of duplicates. During the identification phase, the following exclusion criteria were applied to the databases Scopus, Web of Science, and PubMed: only articles published between 2019 and 2024; scientific articles; peer-reviewed journals; articles written exclusively in English; exclusion of review articles (specific to Web of Science).

All data extracted from the databases were analysed using the Rayyan platform, which was used to exclude duplicates and facilitate the "screening" and "full-text screening" stages. After duplicate removal, titles and abstracts were reviewed, considering only those directly related to the review's objective. In cases of doubt, articles were retained for full-text screening. During the full-text screening phase, articles were selected based on predefined inclusion and exclusion criteria, with all exclusions duly justified and recorded.

The study selection process involved two independent reviewers. Disagreements during the screening and full-text screening phases were resolved through consensus. Studies meeting the predefined criteria were downloaded from online repositories. Two independent reviewers collected and organised data relevant to the review's goals into

Table 1 Keywords used in database searches

Database	Keywords
Scopus	TITLE-ABS-KEY(("ultraviolet radiation" OR "UV radiation" OR "ultraviolet") AND ("occupational exposure" OR "workplace exposure" OR "occupational health") AND ("health effects" OR "cancer" OR "photodamage" OR "diseases"))
	TITLE-ABS-KEY(("ultraviolet radiation" OR "UVR" OR "sunlight") AND ("occupational exposure" OR "work* exposure") AND ("health effects" OR "photodamage" OR "cancer" OR "diseases"))
	TITLE-ABS-KEY(("ultraviolet radiation" OR "UV exposure" OR "solar radiation") AND ("Occupational exposure" OR "workplace exposure") AND ("health effects" OR "adverse health effects" OR "cancer" OR "disorders"))
Web of Science (all data bases)	("ultraviolet radiation" OR "UV radiation" OR "ultraviolet") AND ("occupational exposure" OR "workplace exposure" OR "occupational health") AND ("health effects" OR "cancer" OR "photodamage" OR "diseases") (Topic)
	("ultraviolet radiation" OR "UVR" OR "sunlight") AND ("occupational exposure" OR "work* exposure") AND ("health effects" OR "photodamage" OR "cancer" OR "diseases") (Topic)
	("ultraviolet radiation" OR "UV exposure" OR "solar radiation") AND ("Occupational exposure" OR "workplace exposure") AND ("health effects" OR "adverse health effects" OR "cancer" OR "disorders") (Topic)
PubMed	(("ultraviolet radiation"[All Fields] OR "UV radiation"[All Fields] OR "ultraviolet"[All Fields]) AND ("occupational exposure"[All Fields] OR "workplace exposure"[All Fields] OR "occupational health"[All Fields]) AND ("health effects"[All Fields] OR "cancer"[All Fields] OR "photodamage"[All Fields] OR "diseases"[All Fields]))
	(("ultraviolet radiation"[All Fields] OR "UVR"[All Fields] OR "sunlight"[All Fields]) AND ("occupational exposure"[All Fields] OR "work* exposure"[All Fields]) AND ("health effects"[All Fields] OR "photodamage"[All Fields] OR "cancer"[All Fields] OR "diseases"[All Fields]))
	(("ultraviolet radiation"[All Fields] OR "UV exposure"[All Fields] OR "solar radiation"[All Fields]) AND ("Occupational exposure"[All Fields] OR "workplace exposure"[All Fields]) AND ("health effects"[All Fields] OR "adverse health effects"[All Fields] OR "cancer"[All Fields] OR "disorders"[All Fields]))

an Excel sheet. When necessary, a third reviewer was consulted to ensure consistency in the data extraction process.

The extracted data were synthesised and evaluated using summary tables containing information addressing the review's objectives and the quality appraisal of each study, including the following details: author, year, country, objective, population, UV radiation type, health effect, sun protection, UVR exposure dose, prevalence/risk rate, or statistics and limitations identified in each study. Primary results addressed health effects associated with occupational exposure, while secondary results evaluated factors such as the profession and sun protection use within study populations. Variables without available data were excluded from the analysis for those specific variables. Variables were selected based on their relevance for characterising the health effects of occupational solar UVR exposure, ensuring a detailed analysis of the relationship between them.

This systematic review adopted a qualitative approach to identify health effects associated with occupational solar UVR exposure, as the primary objective did not involve quantitative analysis of traditional effect measures such as odds ratios or mean differences. Results were evaluated based on exposure measures (e.g., SED/year and/or J/m^2) and the prevalence of observed effects in each study. These qualitative measures were chosen for their relevance in characterising UVR-related effects in occupational contexts. The information obtained was complemented by analysing the quality of the study sources, quartiles, and impact factors (2023), using Scimago (*Scimago Journal & Country Rank*, n.d.) and official scientific journal websites. Confidence in the evidence was not assessed.

2.2 Risk of bias assessment

The risk of bias of the included studies was assessed using ROBINS-I (Risk of Bias in Non-randomised Studies of Interventions) tool developed by the Cochrane Bias Methods Group [78]. This tool is designed to evaluate the internal validity of non-randomised observational studies. It includes seven domains: (1) bias due to confounding, (2) bias in the selection of participants, (3) bias in the classification of exposures, (4) bias due to deviations from intended exposures, (5) bias due to missing data, (6) bias in the measurement of outcomes, and (7) bias in the selection of the reported result. Each domain was rated as low, moderate, severe, or critical risk of bias, and an overall judgement was determined based on the highest level of risk identified across domains. Two independent reviewers conducted the assessments, and disagreements were resolved through discussion or consultation with a third reviewer.

Given the objectives of this review, studies were not excluded based on reported biases. Instead, the nature of these sources was observed, and necessary cautions were taken in interpreting the results when applicable, considering the potential impact of these limitations.

3 Results

3.1 Study selection

This systematic review details the study selection process following the guidelines of the PRISMA 2020 statement [55]. The PRISMA 2020 flow diagram, represented in Fig. 1, provides a clear visual representation of the study selection process, highlighting the total number of articles analysed and excluded at each selection stage.

During the identification phase, a comprehensive search was conducted in the databases outlined in the methodology section, resulting in 5,656 identified articles. Following this, exclusion and inclusion criteria were applied as previously described. Of these, 4190 articles were excluded based on publication date (only articles from 2019 to 2024 were considered), 275 based on article type (only scientific articles were included), 61 based on language (English only), and 91 for other reasons (e.g., review articles excluded in Web of Science). Additionally, 708 duplicate articles were removed through automated procedures. This process resulted in 331 articles for the screening phase. Subsequently, after reviewing the titles and abstracts, 284 articles were excluded as they did not meet the review's objective or the predefined inclusion and exclusion criteria. Finally, the full texts of 47 articles identified as potentially eligible during the screening phase were reviewed.

Despite efforts, including searches in alternative databases and direct contact with study authors, access to two scientific articles identified as potentially eligible during the screening phase was not possible. This limitation was duly recorded and highlighted in the PRISMA 2020 flow diagram (Fig. 1). The inaccessibility was due to access barriers and lack of response from the authors. Although these articles were not included in the analysis, their exclusion is considered not to compromise the robustness of this systematic review's results.

After a detailed analysis and application of inclusion and exclusion criteria to each article during the full-text screening phase, 29 articles were excluded. Consequently, 16 articles were included for qualitative analysis, forming the evidence base for the discussion of this systematic review's results.

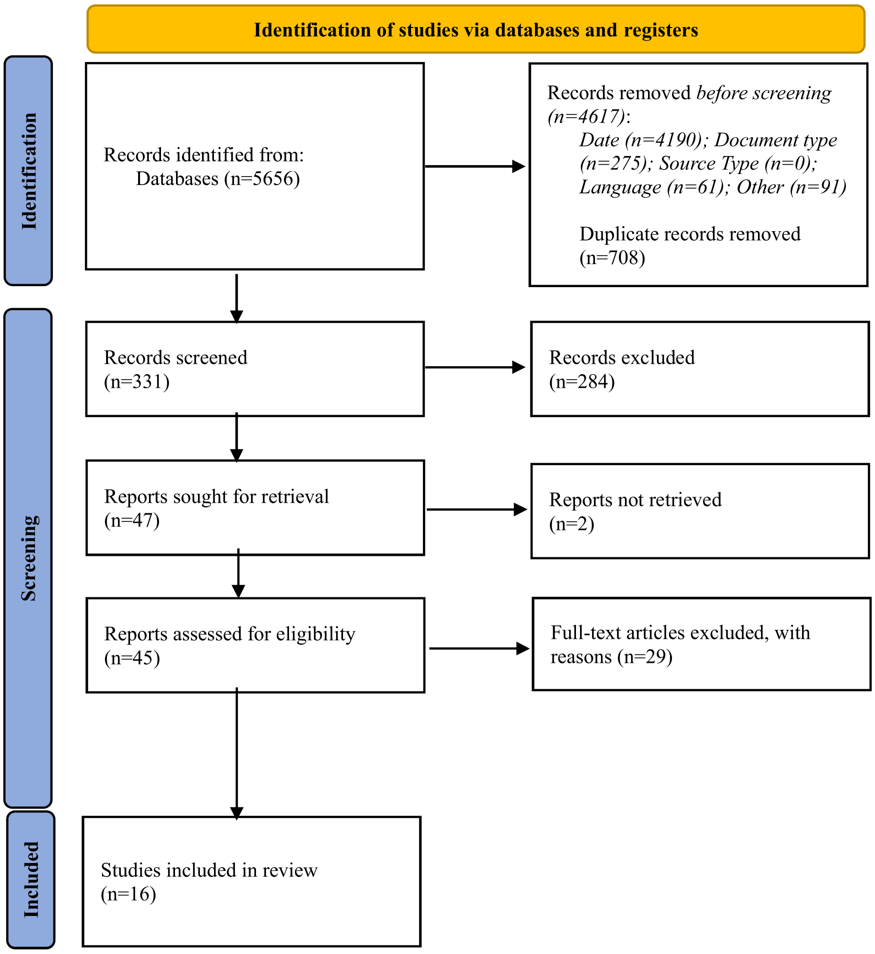

Fig. 1 Flow diagram of the research, adapted from Page et al. [55]

Table 2 Reasons for exclusion of articles during full-text screening

Study	Reason for exclusion
Batsungnoen et al. [6], Cai, [13], Chen [14], Coutinho, [17], D'Souza, [21], Gallo, [23], Ioannou, [36], Koh, [40], Navarro-Bielsa [51], Niu, [52], Olsen et al. [53], Petersen [64], Ragan, [66], Reynolds, [67], Samuel [33, 70, 77, 91]	Lack of direct relationship between solar UVR exposure and a specific health effect (n = 18)
Borik-Heil et al. [10], Kasumagic-Halilovic, [38], Navarro-Bielsa, [49], Navarro-Bielsa, [50], Parks, [58], Puthran, [65], Vats, [86]	Conducted in non-occupational contexts (n = 7)
Ghasemi et al. [24], Gobba, [27], Labrèche, [41], Park, [57]	Focused on non-solar UVR sources (n = 4)

The reasons for the exclusion of the 29 articles during the full-text screening phase are detailed in Table 2. The most common reasons included the lack of a direct relationship between solar UVR exposure, and a specific health effect (18 articles) and studies conducted in non-occupational contexts (7 articles).

3.2 Study characteristics

The studies included in this systematic review investigated the health effects associated with occupational solar UVR exposure across various professional and geographical contexts, encompassing 16 articles published between 2019 and 2023.

The selected studies were conducted in different regions worldwide, including Europe (United Kingdom, Italy, Germany, Romania, Denmark, Norway, Finland, Iceland, and Sweden) [8, 12, 15, 28, 32, 42, 48, 54, 59, 60, 87], North America (Canada and the United States) [43, 62], Asia (Iran and South Korea [69, 76] and Oceania (Australia) [19]. This geographical distribution enabled a comprehensive analysis of UV exposure conditions, even revealing variability in climate types. Table 3 characterizes the studies according to their sources, namely quartile and impact factor (2023). It seems that most of the studies are quartiles and high impact factors, except only three studies from Q3 and Q4.

The results of this systematic review are presented descriptively and summarised in tables, considering the diversity of included studies as well as the quality of sources from each article. Table 4 contains the data extracted from each analysed study.

Some studies identified specific professions, while others categorised workers into broader groups, such as outdoor workers.

The studies included outdoor workers from various sectors, such as agriculture, fishing, construction, gardening, mountain guiding, dock work, unskilled labour, carpentry, and offshore work [15, 28, 32, 42, 48, 62, 76]. Other studies examined workers in professions like doormen, administrative staff, crane operators, blacksmiths, navy personnel, teachers, and radiologists [19, 28, 43, 87]. Some studies did not specify professions, referring only to workers exposed to solar UVR, with some categorised as outdoor workers [8, 12, 59, 60, 69].

The health effects observed in these studies, resulting from occupational solar UVR exposure, included non-melanoma skin cancer (NMSC) (basal cell carcinoma (BCC) and squamous cell carcinoma (SCC); malignant cutaneous melanoma; cataracts and eye damage; facial wrinkles; photoageing; sunburns; increased prevalence of actinic keratosis; lip cancer; decreased epidermal thickness; the increased blood vessel depth [8, 12, 15, 19, 28, 32, 42, 43, 48, 54, 62, 69, 76, 87]. Additionally, there was an association with increased tumour size and thickness [12]. On the other hand, moderate solar UVR exposure was linked to reduced risks of colon and prostate cancer [59, 60].

Table 3 Quartile and impact factor (2023) of scientific journals for each study

Journal	Quartile according to Scimago [75]	Impact factor (2023)
Environmental Research [59]	Q1	7.7
Human Reproduction [43]	Q1	6.0
International Journal of Hygiene and Environmental Health [69]	Q1	4.5
Cancers [15]	Q1	4.5
Journal of Photochemistry and Photobiology B: Biology [19]	Q1	3.9
American Journal of Industrial Medicine [42]	Q1	2.7
Photodermatology, Photoimmunology & Photomedicine [28]	Q1	2.5
Archives of Dermatological Research [54]	Q1	1.8
International Journal of Environmental Research and Public Health [87]	Q2	4.614
Acta Oncologica [48]	Q2	3.1
International Archives of Occupational and Environmental Health [62]	Q2	3.0
Journal of Occupational Health [76]	Q2	2.6
Cancer Epidemiology [60]	Q2	2.4
Journal of Occupational Medicine and Toxicology [8]	Q3	2.9
Wilderness & Environmental Medicine [32]	Q3	1.4
Romanian Medical Journal [12]	Q4	0.3

Table 4 General data extracted from the studies

Author	Year	Country	Objective	Population	Profession/professional group	UV radiation type	Health effect	Sun protection	UVR exposure dose	Prevalence/risk rate (%)	Limitations
Harkensee et al. Clique ou toque aqui para introduzir texto.	2019	United Kingdom	Analyse occupational risks and their impact on quality of life	67 British mountain guides	Mountain guides	UV	Chronic eye problems, skin cancer	Sunscreen; hats	20–50 SED/year; higher at elevated altitudes	5% for skin cancer, 8% for eye problems	Low response rate (32%); voluntary, anonymous, and self-reported survey; lack of standardised questionnaire
Collatuzzo et al. Clique ou toque aqui para introduzir texto.	2023	Italy	Estimate cases and deaths from cancers related to occupational exposure to carcinogens	Italian workers	Farmers and factory operators	UV	Melanoma, NMSC	Not reported	15 J/m^2 estimated for agricultural occupations	1.0% for melanoma; other types not specified	Underestimation of data, variability in exposure levels, and potential confounding by recreational sun exposure and genetic factors
Bauer et al.	2020	Germany	Assess the risk of developing BCC	643 patients with BCC	Outdoor workers	UV	BCC	Sunscreen; hats (irregular use)	Not specified	Twice the risk in occupationally exposed areas	Difficulty in accurately measuring cumulative exposure; memory bias; potential selection errors among controls
Peters et al.	2019	Canada	Estimate cases of non-melanoma skin cancer attributable to occupational solar UVR exposure	Workers	Farmers, construction workers, others	UV	NMSC	Sunscreen (low usage: 30%)	Not specified	6.31% of NMSC attributed to occupational UV	Population-based data interpolation; risk estimates based on meta-analyses without exposure level differentiation

Table 4 (continued)

Author	Year	Country	Objective	Population	Profession/professional group	UV radiation type	Health effect	Sun protection	UVR exposure dose	Prevalence/risk rate (%)	Limitations
Butacu et al.	2020	Romania	Analyse clinical and histopathological characteristics of non-melanoma skin cancer in relation to cumulative occupational exposure doses	25 outdoor workers	Construction workers, farmers, athletes, others	UV	NMSC; larger, thicker, and faster-growing tumours	Not specified	30–40 SED/year exposure average	Twice as high as the general population; higher in high-risk areas	Small sample size; limited to Romanian context; lack of leisure-time exposure data; potential selection bias
Pedersen et al.	2022	Denmark	Investigate the association between occupational solar UVB exposure and colorectal cancer risk	12,268 colorectal cancer risk cases, 81,985 controls	Outdoor workers	UVB	Modest protective effect against colon cancer, especially in women	Not reported	Low levels, < 10 SED/year	Reduced risk of colon cancer with high cumulative exposure (OR = 0.90)	Limitations in assessing non-occupational UV exposure; registry-based data
Dexter et al.	2020	Australia	Assess relative risks of skin cancer	Teachers from 1,578 schools in Queensland	Teachers	UV	BCC, squamous cell carcinoma	Hats; sunscreen	15–35 SED/year; higher during school breaks	Up to 32% increased risk of BCC and 64% of SCC in high-exposure areas	Limitations in cumulative exposure calculations; lack of leisure-time exposure data
Saeedi et al.	2022	Iran	Assess the disease burden attributable to occupational solar UVR exposure	Outdoor workers in Iran	Not specified	UV	Cataracts, malignant cutaneous melanoma, squamous cell carcinoma, sunburns	Not specified	60 J/m^2 annual average for agricultural workers	DALY increased from 2,442 to 2,907 between 2005 and 2019	Lack of recreational exposure data; estimates used for occupational exposure and attributable disease data; potential bias in provincial and temporal data

Table 4 (continued)

Author	Year	Country	Objective	Population	Profession/professional group	UV radiation type	Health effect	Sun protection	UVR exposure dose	Prevalence/risk rate (%)	Limitations
Vimercati et al.	2020	Italy	Analyse the prevalence of actinic keratosis	921 military personnel	Navy personnel	Solar UV	Prevalence of actinic keratosis; lesions in exposed areas	Not specified	Not specified	23.5% AK prevalence; 86.2% in areas chronically exposed to the sun	Lack of detailed data on UV exposure; study limited to male population; selection bias by including only outdoor-active military personnel
Shin et al.	2019	South Korea	Investigate occupational differences in standardised mortality rates for NMSC and melanoma	594 individuals	Farmers, fishermen, foresters, and office workers	UVB	NMSC and melanoma	Not reported	Estimated 25–40 SED/year for outdoor workers	SMR for NMSC: 553 (men), 575 (women); SMR for melanoma: 453 (men)	Limitations in data on occupational UV exposure; lack of adjustment for demographic and socioeconomic factors; inability to distinguish between skin cancer subtypes
Pedersen et al.	2022	Denmark	Assess the association between occupational UVB exposure and prostate cancer risk	12,268 prostate cancer cases and 61,340 controls	Outdoor workers	UVB	Reduced risk of prostate cancer	Sunscreen (low usage: 20%)	10–20 SED/year; estimated from occupational data	OR = 0.93 for occupational exposure; OR = 0.90 for high cumulative exposure	Lack of data on non-occupational UV sources; use of exposure matrix; dietary variables or vitamin D supplementation not considered; selection bias
Mroueh et al.	2023	Denmark, Finland, Iceland, Norway, Sweden	Assess variations in lip cancer incidence across different occupations	14.9 million individuals	Fishermen, farmers, gardeners	UVA and UVB	Lip cancer	Hats	40 J/m^2 cumulative average in outdoor occupations	SIR: 2.26 for fishermen, 1.60 for farmers and gardeners	Does not differentiate between internal and external lip cancer; lack of information on smoking, alcohol, and sunscreen use; occupational exposure calculated based on the first census participation
Olsen et al.	2022	Denmark	Investigate epidermal thickness and blood vessel depth using dynamic optical coherence tomography (D-OCT) in relation to occupational UVR exposure	249 adults	Not specified	UVA and UVB	Decreased epidermal thickness and increased blood vessel depth	Sunscreen	15–25 SED/year with seasonal fluctuations	Strong seasonal variation; reduction of 0.113–0.288 µm per day between August and December	Measurements based on self-reports; cross-sectional study limits analysis; variability due to environmental factors, such as ambient temperature

Table 4 (continued)

Author	Year	Country	Objective	Population	Profession/professional group	UV radiation type	Health effect	Sun protection	UVR exposure dose	Prevalence/risk rate (%)	Limitations
Grandahl et al.	2019	Denmark	Investigate photoageing, actinic keratosis, and keratinocyte cancer	234 workers (155 outdoor, 79 indoor)	Gardeners, unskilled workers, road workers, dock workers, carpenters, masons, doormen, administrative staff, crane operators, blacksmiths	UVA and UVB	Facial wrinkles and actinic keratosis (outdoor workers)	Sunscreen; hats	30 SED/year on average for teachers	10.3% AK in outdoor workers; 5.1% in indoor workers	Lack of data on leisure-time exposure; UV exposure measured only in summer; lack of adjustment for lifestyle factors, such as sunscreen use
Mai et al.	2022	United States	Assess the association between reproductive factors, use of exogenous hormones, and the risk of primary invasive melanoma	46,544 female workers	Radiologists	UV	Melanoma	Not specified, low usage	Not specified	0.95% of participants developed melanoma (444 cases among 46,544)	Self-reported data on reproductive history and hormone use; population included only women
Liu et al.	2021	Norway	Assess the association between UVR exposure and the risk of melanoma and SCC in offshore workers in Norway	27,917 offshore workers (25,215 men, 2557 women)	Offshore workers in the oil sector	UVA and UVB	Increased risk of melanoma and SCC, sunburns, and indoor tanning	Sunscreen	Intermittent high exposure, > 40 SED/year during intense periods	Increased melanoma risk with frequent sunburns and tanning post-age 20 (HR = 2.16 for frequent sunscreen use)	Self-reported data; occupational UV exposure difficult to distinguish from recreational exposure; lack of information on individual risk factors

Regarding the use of sun protection, variability in behaviours was observed. These included the use of sunscreen [8, 19, 28, 32, 42, 54, 60] and hats [8, 19, 28, 32, 48]. However, some studies did not specify the presence of these behaviours, [12, 15, 59, 69, 76, 87], while the study by Mai et al., [43], [43] noted only low usage frequency without detailing the type of protection used.

In terms of measurements of solar UVR exposure, results varied between < 10 to 50 SED/year [12, 19, 28, 32, 42, 54, 59, 60, 76] and 15 J/m^2 to 60 J/m^2 [15, 48, 69]. Other studies did not specify exposure values [8, 43, 62, 87]. A notable limitation identified in multiple studies was the lack of assessment of non-occupational exposure outside working hours [12, 19, 28, 42, 59, 60, 69, 76, 87].

Table 5 presents the observed health effects associated with occupational solar UVR exposure and the professions identified in the 16 studies included in this systematic review. Professions or professional groups were directly extracted from the included studies. It is worth noting that the "outdoor workers" category presents aggregated data. For certain effects, such as "larger tumours," studies did not specify the associated professions, highlighting a limitation. Table 5 reflects both negative effects (e.g., skin cancer and cataracts) and positive effects (e.g., protection against colon cancer), showcasing variability in exposure conditions and occupational and geographical contexts.

Thus, the studies included in this systematic review indicate a clear association between occupational solar UVR exposure and negative health effects, such as NMSC, cataracts, and facial wrinkles. Some positive effects were also noted. Outdoor workers were identified as the most exposed, with exposure levels varying across professions. The synthesis further revealed variability in preventive behaviours, with irregular use of sunscreen and hats among different occupational groups.

Table 5 Observed health effects and associated professions

Observed health effect	Profession/professional group
Increased blood vessel depth [54]	NS
Indoor tanning [42]	Offshore petroleum workers
Skin cancer [32]	Mountain guides
NMSC [12, 15, 62, 76]	Farmers, factory operators, construction workers, athletes, fishermen, foresters, office workers
SCC [19, 42, 69]	Offshore petroleum workers; teachers
BCC [8, 19]	Outdoor workers; teachers
Lip cancer [48]	Fishermen, farmers, gardeners
Cataracts [69]	NS
Decreased epidermal thickness [54]	NS
Melanoma [15, 42, 43, 69, 76]	Farmers, factory operators, fishermen, foresters, office workers, radiologists, offshore petroleum workers
Chronic eye damage [32]	Mountain guides
Prostate cancer protection [60]	Outdoor workers
Colon cancer protection [59]	Outdoor workers
Sunburns [42]	Offshore petroleum workers
Actinic keratosis [28, 87]	Navy personnel, gardeners, unskilled workers, road workers, dock workers, carpenters, masons
Facial wrinkles [28]	Gardeners, unskilled workers, road workers, dock workers, carpenters, masons, doormen, administrative staff, crane operators, blacksmiths
Tumours with faster progression [12]	NS
Larger tumours [12]	NS

NS – Not Specified

Although the descriptive objective of this review prioritised qualitative synthesis, the study quality was considered to assess the robustness of conclusions. While studies conducted in different occupational contexts yielded consistent results, the absence of quantitative data and the heterogeneity of methodologies limited the certainty of the evidence. As a qualitative evaluation strategy, factors such as consistency of results across professions and geographies, methodological quality assessed through risk of bias, and sample robustness were considered.

3.3 Risk of bias in studies

The risk of bias assessment followed the criteria outlined in the ROBINS-I tool [78], as described in the methodology section of this review. Each study was independently evaluated across seven domains: confounding, participant selection, exposure classification, deviations from intended exposures, missing data, outcome measurement, and reporting. For each domain, a rating of low, moderate, serious, or critical risk of bias was assigned based on methodological robustness and clarity of reporting. An overall risk of bias judgement was determined by the highest level of bias identified among domains. Table 6 summarises the results of this evaluation, providing an overview of the methodological quality of the included studies and highlighting the domains most frequently affected by potential bias.

As shown in Table 6, the pattern of risk of bias was largely consistent across domains, with confounding and exposure classification emerging as the most frequent sources of bias. In contrast, outcome measurement and reporting domains generally demonstrated lower risk.

Seven studies were judged to have a serious risk of bias, mainly due to uncontrolled confounding and indirect exposure assessment [12, 15, 32, 62, 69, 76, 87]. In contrast, eight studies were rated as having a moderate overall risk of bias [28, 42, 43, 45, 48, 54, 59, 60]. No study was rated as having a low or critical overall risk of bias. These findings highlight the methodological diversity of observational UVR research and reinforce the need for harmonised exposure measurement protocols and multivariable adjustment frameworks in future studies [78].

Additionally, limitations reported by the study authors included participant selection, self-reporting biases, lack of standardised methods for exposure assessment, unadjusted confounding factors, absence of data on non-occupational exposure, and insufficient temporal and geographical estimates. Small and geographically restricted samples and low response rates may compromise representativeness and limit the generalisability of the results [12, 32]. Studies relying on participant self-reports faced challenges in obtaining accurate data on cumulative solar UVR exposure due to the long-term nature of such studies [8, 54]. The absence of standardised methods for UVR exposure assessment was discussed in several studies, including difficulties distinguishing occupational from recreational exposure and the lack of objective data to estimate cumulative exposure doses [15, 28]. Confounding factors such as smoking, alcohol consumption, and genetic predisposition significantly influenced the observed results in some studies but were not considered [48, 76]. The lack of data on UVR exposure during recreational activities made it challenging to separate occupational from non-occupational exposure [42, 69]. Geographically and temporally limited data further constrained the precision of analyses and conclusions on the global impact of UVR exposure [59, 69].

Table 6 Risk of bias assessment of the included studies using the ROBINS-I tool [78]

Author	1. Bias due to confounding	2. Bias in selection of participants into the study	3. Bias in classification of exposure	4. Bias due to deviations from intended exposure	5. Bias due to missing data	6. Bias in measurement of outcomes	7. Bias in selection of the reported result	Overall risk of bias
(Harkensee & Hillebrandt, 2019)	Serious	Serious	Serious	Low	Low	Serious	Moderate	Serious
(Collatuzzo et al., 2023)	Moderate	Low	Serious	Low	Low	Serious	Low	Serious
(Bauer et al., 2020)	Moderate	Low	Serious	Low	Low	Moderate	Low	Serious
(Peters, Kim, et al., 2019)	Serious	Moderate	Moderate	Low	Low	Moderate	Low	Serious
(Butacu et al., 2020)	Moderate	Low	Moderate	Low	Low	Low	Low	Moderate
(Pedersen & Hansen, 2022a)	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
(Dexter et al., 2020)	Moderate	Low	Serious	Low	Low	Moderate	Low	Serious
(Saeedi et al., 2022)	Moderate	Moderate	Serious	Low	Low	Low	Low	Serious
(Vimercati et al., 2020)	Serious	Low	Serious	Low	Low	Low	Low	Serious
(Shin et al., 2019)	Moderate	Low	Moderate	Low	Low	Low	Low	Moderate
(Pedersen & Hansen, 2022b)	Serious	Low	Moderate	Low	Low	Low	Low	Serious
(Mroueh et al., 2023)	Moderate	Low	Moderate	Low	Low	Low	Low	Moderate
(J. Olsen et al., 2022)	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
(Grandahl et al., 2019)	Moderate	Low	Moderate	Low	Moderate	Low	Low	Moderate
(Mai et al., 2022)	Moderate	Low	Moderate	Low	Low	Low	Low	Moderate

Low Moderate Serious Critical

Statistical significance was stated in the case of $p < 0.05$ and was highlighted by light gray color

4 Discussion

This systematic review identified the health effects arising from occupational exposure to solar UVR. The findings may assist in systematising the existing literature and contribute to the prevention of such exposure. The main results align with the current scientific evidence, indicating a direct association between solar UVR exposure and the development—or, in some cases, prevention—of related health conditions, particularly among individuals engaged in outdoor occupations [66, 94]. Moreover, increased awareness of solar UVR exposure and its association with certain pathologies supports the development of targeted preventive measures [11, 31, 81, 94]. Regarding sunburn and UVR exposure, both are recognised as avoidable causes of skin cancer [18]. It is also worth emphasising that, for outdoor workers, solar UVR represents the most significant occupational carcinogenic agent [39].

4.1 Dermatological effects

Agricultural workers, construction workers, fishermen, and offshore workers are at significantly increased risk of BCC, SCC and NMSC [56]. In the European Union, for instance, more than 14.5 million workers are exposed to UVR, with agricultural and construction sectors being the most affected. Pega et al. [61] estimated that approximately 31% of non-melanoma skin cancer cases between 2000 and 2019 were attributable to occupational UVR exposure. Prolonged, cumulative, and often unprotected exposure further amplifies this risk.

Chronic exposure to UVR also induces photoageing phenomena, including deep wrinkles, loss of skin elasticity, and actinic keratoses. Grandahl et al., [28] demonstrated that outdoor workers exhibit a higher prevalence of such skin alterations compared to their indoor counterparts, reflecting the cumulative impact of solar exposure.

4.2 Ophthalmological effects

The WHO estimates that UVR is responsible for approximately 20% of global cataract cases, with this proportion likely to be higher in occupational contexts [37]. Professions such as fishing, offshore work, and mountain guiding are particularly exposed, due to both direct radiation and reflection from surfaces like water or snow [46, 68].

Recent studies, such as that by Ghasemi et al. [24] have identified significant alterations in the ocular surface of workers chronically exposed to UVR, including increased prevalence of pterygium and changes in corneal thickness. However, the consistent use of eye protection remains limited, thereby compromising the effectiveness of preventive measures.

4.3 Oncological effects

Moderate exposure to UVR, through cutaneous synthesis of vitamin D, has been associated with a reduced risk of certain cancers, such as colorectal and prostate cancer Uçar & Holick, [82]. Studies by Pedersen and Hansen [59] and Vallès et al. [85] suggest an inverse relationship between adequate vitamin D levels and the incidence of these malignancies, indicating potential immunomodulatory and antiproliferative effects.

However, these associations should be interpreted with caution. Many studies fail to adequately control for confounding factors such as diet, physical activity, and vitamin D supplementation. Moreover, the observed protective effects are typically linked to moderate and intermittent exposure, which does not reflect the chronic and intense exposure conditions characteristic of occupational settings Uçar & Holick, [83].

4.4 Economic and social impact

The economic and social burden of UVR-associated diseases is substantial. Mofidi et al. [47] estimated high costs related to the treatment of skin cancers linked to occupational exposure, with repercussions for work absenteeism, loss of productivity, and financial strain on healthcare systems. This reality demands an integrated public and occupational health approach, with targeted policies for the most vulnerable sectors and the formal recognition of UVR as an occupational risk [61].

4.5 Limitations and future research

Bias analysis emphasized that the influencing factors and the challenges in achieving an objective assessment, present significant difficulties in establishing a causal link between exposure and disease development - particularly when it comes to cancer. The methodological heterogeneity across studies limits direct comparability of findings. Most investigations rely on self-reported exposure data, lacking objective measurements such as SED or J/m^2. The absence of standardised protocols hinders the formulation of universally applicable recommendations, underscoring the urgent need for methodological harmonisation in research on occupational UVR exposure [71, 93]. This study does not include a quantitative analysis, as methodological diversity and variations in reporting among the studies prevented its execution.

Another critical challenge is the failure to differentiate between occupational and recreational exposure, introducing considerable bias - particularly in Mediterranean-climate countries. The lack of control for individual factors, such as skin phototype, family history, and lifestyle habits, further weakens the robustness of conclusions drawn [93].

From a methodological perspective, the review process included some restrictions that may have influenced the findings. Limiting the selection to articles in English may have excluded relevant evidence published in other languages, potentially introducing selection bias [81, 94].

The practical implications of this review's findings are considerable. It is essential for governments, employers, and other entities to implement measures and policies to protect workers exposed to solar UVR. Proper use of personal protective equipment (PPE), such as wide-brimmed hats, long-sleeved shirts, long trousers, and sunscreen, along with appropriate training on their use, is crucial, given the results of this review. Furthermore, occupational health services could prescribe regular skin cancer screening, particularly for high-risk workers. Controlled UVR exposure should also be considered, as it can provide health benefits [61].

Developing policies that establish occupational solar UVR exposure limits is essential [26]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) states that acceptable daily exposure is between 1.0 and 1.3 Standard Erythemal Doses (SED), with 1 SED corresponding to 100 J/m^2 [96]. In Germany, it is recognised that working outdoors for more than one hour between 11 am and 4 pm for over 50 days, from April to September, increases the risk of adverse skin effects [92].

In terms of future research, the findings of this review point to the need for studies investigating cumulative solar UVR exposure over a lifetime and its long-term impacts in various occupational contexts [42]. Future studies should also explore interactions between worker habits, such as alcohol and tobacco consumption, which may relate to some health effects identified in this systematic review, such as lip cancer [48]. Environmental aspects, particularly climate change, could also be considered in future research [9, 25].

Finally, the use of more precise technologies could improve the accuracy of exposure data, aiding a better understanding of the effects of solar UVR exposure and assessing the effectiveness of prevention and protection measures [30, 63].

5 Conclusion

Occupational exposure to solar UVR poses a significant health risk for outdoor workers, with well-documented impacts including skin neoplasms, ocular damage, and photoageing. Although moderate exposure may offer potential benefits, such as vitamin D synthesis, the risks associated with chronic and intense exposure are evident and call for robust preventive measures.

The implementation of protective strategies, including the provision of PPE, adjustment of work schedules, and regular health screenings, is essential to reducing associated morbidity. Recognising UVR as an occupational hazard and establishing legally binding exposure limits must be prioritised to ensure adequate worker protection. The methodological limitations identified reinforce the need for more rigorous and integrated future research.

This systematic review provides a valuable contribution to the management of occupational UVR related risks, offering a reference framework for the development of evidence based occupational health policies and strategies.

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