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ORIGINAL PAPER

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OUTDOOR WORK AND SOLAR RADIATION EXPOSURE: EVALUATION METHOD FOR EPIDEMIOLOGICAL STUDIES

PRACA NA WOLNYM POWIETRZU A NARAŻENIE NA PROMIENIOWANIE SŁONECZNE – METODA OCENY DO STOSOWANIA W BADANIACH EPIDEMIOLOGICZNYCH

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ABSTRACT

Background: The health risk related to an excessive exposure to solar radiation (SR) is well known. The Sun represents the main exposure source for all the frequency bands of optical radiation, that is the part of the electromagnetic spectrum ranging between 100 nm and 1 mm, including infrared (IR), ultraviolet (UV) and visible radiation. According to recent studies, outdoor workers have a relevant exposure to SR but few studies available in scientific literature have attempted to retrace a detailed history of individual exposure. **Material and Methods:** We propose a new method for the evaluation of SR cumulative exposure both during work and leisure time, integrating subjective and objective data. The former is collected by means of an interviewer administrated questionnaire. The latter is available through the Internet databases for many geographical regions and through individual exposure measurements. The data is integrated into a mathematical algorithm, in order to obtain an esteem of the individual total amount of SR the subjects have been exposed to during their lives. **Results:** The questionnaire has been tested for 58 voluntary subjects. Environmental exposure data through online databases has been collected for 3 different places in Italy in 2012. Individual exposure by electronic UV dosimeter has been measured in 6 fishermen. A mathematical algorithm integrating subjective and objective data has been elaborated. **Conclusions:** The method proposed may be used in epidemiological studies to evaluate specific correlations with biological effects of SR and to weigh the role of the personal and environmental factors that may increase or reduce SR exposure. Med Pr 2016;67(5):577–587

Key words: occupational exposure, optical radiation, outdoor work, exposure assessment, solar radiation, ultraviolet radiation

STRESZCZENIE

Wstęp: Ryzyko zdrowotne związane z nadmiernym narażeniem na promieniowanie słoneczne (solar radiation – SR) jest dobrze znane. Słońce stanowi główne źródło promieniowania optycznego wszystkich zakresów częstotliwości, które obejmuje część widma elektromagnetycznego w zakresie od 100 nm do 1 mm, w tym podczerwień (infrared – IR), ultrafiolet (ultraviolet – UV) i promieniowanie widzialne. Według najnowszych badań osoby pracujące na wolnym powietrzu mogą być znacznie narażone na promieniowanie słoneczne, ale w niewielu badaniach odtworzono szczegółową historię indywidualnej ekspozycji. **Materiał i metody:** W artykule zaproponowano nową metodę oceny skumulowanego narażenia na SR podczas pracy i w czasie wolnym, uwzględniającą dane subiektywne i obiektywne. Pierwsze z nich są zbierane w wywiadzie, drugie można uzyskać z baz internetowych dla regionów geograficznych i poprzez indywidualne pomiary narażenia. Dane są łączone za pomocą algorytmu matematycznego w celu uzyskania wartości indywidualnego całkowitego narażenia na SR badanych osób w trakcie ich całego życia. **Wyniki:** Kwestionariusz przetestowano wśród 58 ochotników. Dane dotyczące narażenia na SR w 3 różnych miejscach we Włoszech w 2012 r.

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uzyskano z internetowych baz danych. Pomiar indywidualnego narażenia na SR u 6 rybaków wykonano elektronicznym dozymetrem UV. Opracowano również matematyczny algorytm scalania danych subiektywnych i obiektywnych. **Wnioski:** Proponowana metoda może być stosowana w badaniach epidemiologicznych do określenia zależności między efektami biologicznymi a narażeniem na promieniowanie słoneczne oraz do oceny roli czynników osobniczych i środowiskowych, które mogą zwiększać lub zmniejszać narażenie na promieniowanie słoneczne. Med. Pr. 2016;67(5):577–587

Słowa kluczowe: narażenie zawodowe, promieniowanie optyczne, praca na wolnym powietrzu, ocena narażenia, promieniowanie słoneczne, promieniowanie ultrafioletowe

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INTRODUCTION

The interaction of solar radiation (SR) with biological tissues may induce several effects, some of which with positive consequences for human health (e.g., SR promotes vitamin D metabolism, preventing rickets and osteoporosis), but the most of that is adverse health impact [1]. The Sun represents the main exposure source for all the frequency bands of optical radiation, that is the part of the electromagnetic spectrum ranging between 100 nm and 1 mm, including infrared (IR), ultraviolet (UV) and visible radiation.

It should be noted that the SR that reaches the Earth's surface has a spectral composition significantly different from that emitted by the Sun. This is due primarily to an atmospheric absorption of ultraviolet radiation (UVR) by various gaseous components, in particular the ozone, which blocks all wavelengths of less than 290 nm, and so all the UVC and a significant part of the UVB. Due to the filtering effect performed by the atmosphere, the SR to the Earth's surface is composed largely of frequencies within the IR and the visible radiation which constitute respectively the 45% and about the 50% of the SR, and only for the 5% of UVR. Although it covers only a minimal part of the spectrum reaching the Earth's surface, the UVR represents the major risk for human health because it is able to induce the most severe biological effects. Thus, SR may be responsible for acute and chronic adverse effects particularly to the skin and the eyes. It has to be noted that both UV radiation and SR have been classified by the International Agency for Research on Cancer (IARC) as human carcinogens, group I [1–4].

The quality and quantity of SR that reaches the Earth's surface varies with the elevation angle of the Sun above the horizon, so the exposure may change depending from the time of the day, the day of the year, and geographical location (altitude and latitude). Also the composition of the atmosphere, the presence of pollutants and the meteorological conditions (clouds, rain, snow, etc.) may influence the amount of UVR that reaches the ground: they may absorb it and thus they may cause a reduction of the exposure but they may also redirect UV rays with different mechanisms, like refraction, diffusion and reflection.

Finally, the type of surface may increase SR exposure, for example fresh snow reflects up to 90% of UV rays. In addition, there are also several individual factors that may influence SR exposure. First of all, occupational activity: outdoor work is a recognized risk factor for many cutaneous and ocular diseases related to UVR exposure, in particular if workers aren't provided with adequate protective equipment and in the absence of shelters in the working area [3–6]. According to recent studies, outdoor workers have a relevant exposure to SR and the exposure levels largely exceed the limit of 30 J/m^2, effective radiant exposure (H_{eff}) referred to a daily exposure of 8 h. This limit was set in the European Directive 2006/25/EC to prevent the adverse effects of non-coherent artificial optical radiation with a wavelength of 180–400 nm (UVA, UVB and UVC) [7].

It is estimated that about 14.5 million workers in Europe are exposed to SR for at least 75% of their working time, the vast majority of which (90%) are generally male. Data from the European Agency for Safety and Health at Work shows that UVR is a carcinogen in 36 employment sectors of the European Union and for 11 of these it ranks first among the other carcinogens [8].

Other important individual aspects that may influence SR exposure are protecting behaviors, such as the regular use of covering clothes, sunglasses and a hat, the application of sunscreen protections and the interruption of exposure during the central hours of the day, when the SR is more intense. These aspects may be important to reduce SR exposure, both during working and leisure activities, especially during summer vacation's periods [9,10]. Finally, one of the most important factor that influences skin exposure to SR is individual characteristics. People with fair photo-types, such as Fitzpatrick's photo-types I and II, are more sensitive to the UV damage [11], and this factor is relevant also among outdoor workers [12].

As previously mentioned, solar ultraviolet radiation may cause several acute and chronic effects, mainly ocular and cutaneous, but also immunological and various others. According to a recent World Health Organization (WHO) review, acute ocular effects with a strong evidence of causality include photokeratitis, photoconjunctivitis and solar retinopathy; chronic diseases include pterygium, cortical cataract and epithelial cancers of the cornea and conjunctiva. Regarding the skin, acute effects with strong evidence of causality include sunburns and photodermatoses; chronic effects include photoaging and solar keratoses, and skin cancers: basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and malignant melanoma (MM). The only immune effect due to SR exposure with a strong evidence of causality in the WHO's review is the reactivation of latent herpes labialis infections [1].

Several studies show that outdoor workers have an increased risk of developing SR related diseases [1,3–6] but the vast majority of the studies assess the individual sun exposure through subjective questionnaires or referring to environmental factors like the UV index of the place of usual activity or using biological parameters that estimate the UV damage or with a retrospective classification of the jobs as outdoor or indoor. Only few studies adopted quantitative or detailed semi-quantitative tools to assess quantitative exposure [3–6]. On the contrary, there are many studies that provide an objective evaluation of acute SR exposure in a short-period of time using individual UV dosimeters [13–21].

Few examples of large-scale quantitative and semi-quantitative monitoring of UV exposure for a long period of time were that of Germany [22], the United States [23] and Australia [24]. In the German project carried out by the Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin – BAuA), various outdoor occupations were monitored with personal UV dosimeters along the year on week days, at weekends and during holidays, considering 19 specific body parts [22]. In the American study an integration of objective and subjective data was performed by Rosenthal et al. [23], developing a model of ocular and facial skin exposure to UVB combining interviews on previous relevant outdoor work and leisure activities, use of protective equipment and laboratory measurements of UV radiant exposure in watermen. Similarly in Australia, McCarty et al. [24] developed a simplified model for quantifying lifetime ocular UVB exposure considering the ambient UVB levels, the duration of outdoor exposure, the proportion of ambient UVB reaching the eye and the use of ocular protection. These studies are relevant to understand how individual and environmental factors may modify SR exposure, influencing the induction of long-term adverse effects.

Objective

Considering these premises, the aim of our work is to present a new method for a comprehensive evaluation of individual and environmental SR exposure, useful for an application in epidemiological studies. The assessment of cumulative SR exposure has to take into account all the relevant factors and characteristics influencing the exposure, adopting a final algorithm which integrates subjective and objective data, both related to occupation and leisure-time. An adequate esteem of the amount of solar UV radiation received by specific target organs in a period of several years should be useful to correlate chronic SR-related adverse effects – and their specific characteristics – with the cumulative working and leisure SR exposure.

MATERIAL AND METHODS

Collection of subjective SR exposure data

To collect subjective data a new interviewer administrated questionnaire was developed, based on the individual and environmental factors influencing SR exposure considered by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [5–6].

The items of the questionnaire, that assesses exposure modes during work and leisure activities (Table 1), have been elaborated by the authors, a team of occupational physicians and experts in optical radiation and industrial hygiene. The study was conducted in accordance with all national regulations and with principles of the Declaration of Helsinki. Complete information regarding the study was given, and subjects were informed that participation was voluntary, and that they were free to withdraw from the study at any time. Written informed consent was collected. Nobody refused to participate or withdrew during the study. A pilot administration of the questionnaire was performed by one of the authors (A. Modenese) in a sample of voluntary subjects afferent to an Italian dermatologic clinic for previously diagnosed solar-related skin lesions or for suspected lesions, from January 2014 to August 2015. The following excluding criteria were applied: an inadequate ability to understand the Italian language, an age < 40 years old and length of employment shorter than 10 years. The questionnaire takes 15–40 min and the administration was performed while patients were waiting for their turn to undergo the dermatologic examination.

The questionnaire is composed of 3 sections. To answer the questions of each section, the respondent has to consider only the months of the year between March and October (except for vacations on the snow), when the exposure to SR is more intense. At the beginning of each section, the interviewer has to define the period of life, in number of years, the section refers to. In each section, the 12 items investigate the type of outdoor activity, the total time people spend outside during the activity and main personal habits that may influence SR exposure. The habits are investigated by means of a 5-point Likert type frequency scale, which ranges from 0, meaning "never adopted this habit during the activity" to 5 "always adopted this habit during the activity." The administrator has to fill in a new copy of a section – henceforth "tab" – if a change in the exposure habits is detected. Regarding the work exposure section, a new tab is administered in the following circumstances:

- job change (e.g., for 10 years of employment in agriculture, then in the construction sector),
- workplace change, when it is supposed that there is a significant change in the SR exposure (e.g., different UV index),
- work tasks change (for the same job, we may have different tasks with different position adopted during work, different number of hours in the sunlight and different protective equipment).

Table 1. Questionnaire of solar radiation exposure evaluation
Tabela 1. Kwestionariusz oceny narażenia na promieniowanie słoneczne

Working time exposure Narażenie w czasie pracy	Leisure time exposure (not vacation) Narażenie w czasie wolnym (oprócz wakacji)	Vacation exposure Narażenie w czasie wakacji
1. Type of outdoor job / Rodzaj pracy na wolnym powietrzu	1. Place of residence (latitude) / Miejsce zamieszkania (szerokość geograficzna)	1. Place of vacation (latitude) / Miejsce spędzania wakacji (szerokość geograficzna)
2. Job place / Miejsce wykonywania prac	2. Place of residence (altitude) / Miejsce zamieszkania (wysokość n.p.m.)	2. Place of vacation (altitude) / Miejsce spędzania wakacji (wysokość n.p.m.)
3. Time spent outdoor / Czas spędzony na wolnym powietrzu	3. Time spent outdoor / Czas spędzony na wolnym powietrzu	3. Time spent outdoor / Czas spędzony na wolnym powietrzu
4. Lunch time and place / Czas i miejsce spożywania obiadu	4. Practice of outdoor sports / Sport uprawiany na wolnym powietrzu	4. Frequency of sunburns / Częstość oparzeń słonecznych
5. Prevalent postures / Najczęstsza pozycja ciała	5. Exposure to sunbeds / Korzystanie z solarium	5. Use of suntan lotion / Stosowanie preparatów ułatwiających opalanie
6. Time in the shade / Czas spędzony w cieniu	6. Time in the shade / Czas spędzony w cieniu	6. Time in the shade / Czas spędzony w cieniu
7. Time near reflecting surfaces / Czas spędzony w pobliżu przedmiotów/powierzchni odbijających światło	7. Time near reflecting surfaces / Czas spędzony w pobliżu przedmiotów/powierzchni odbijających światło	7. Time near reflecting surfaces / Czas spędzony w pobliżu przedmiotów/powierzchni odbijających światło
8. Time a hat is worn / Czas noszenia nakrycia głowy	8. Time a hat is worn / Czas noszenia nakrycia głowy	8. Time a hat is worn / Czas noszenia nakrycia głowy
9. Time sunglasses are worn / Czas noszenia okularów przeciwsłonecznych	9. Time sunglasses are worn / Czas noszenia okularów przeciwsłonecznych	9. Time sunglasses are worn / Czas noszenia okularów przeciwsłonecznych
10. Time spectacles are worn / Czas noszenia okularów	10. Time spectacles are worn / Czas noszenia okularów	10. Time spectacles are worn / Czas noszenia okularów
11. Time protective clothes are worn / Czas noszenia odzieży ochronnej	11. Time protective clothes are worn / Czas noszenia odzieży ochronnej	11. Time protective clothes are worn / Czas noszenia odzieży ochronnej
12. Time with sunscreen protections / Czas korzystania z filtrów przeciwsłonecznych	12. Time with sunscreen protections / Czas korzystania z filtrów przeciwsłonecznych	12. Time with sunscreen protections / Czas korzystania z filtrów przeciwsłonecznych

The second section of the questionnaire investigates leisure outdoor activities and new tabs have to be administered when there is:

- residence change, when it is supposed that there is a significant change in the SR exposure (e.g., different UV index),
- change in the number of days per week the activity is done by the respondent (normally 2 days per week for working people),
- leisure activity change (e.g., a new outdoor activity, such as a new hobby or outdoor sport),
- protective habits change (e.g., the respondent states that he has started to use sunglasses, a hat, sunscreen protections, etc.).

The third section of the questionnaire investigates leisure outdoor activities during vacation periods and if the vacation is spent on the snow the respondents have to also consider the winter months. New tabs have to be administered in the following cases:

- vacation place change, when it is supposed that there is a significant change in the SR exposure (e.g., different UV index) and when there is a change regarding the presence of reflecting surfaces, such as water or snow,
- change in the number of days of vacation per year,
- protective habits change (e.g., the respondent states that he has started to use sunglasses, a hat, sunscreen protection, etc.).

Collection of objective environmental SR exposure data

Meteorological climate data of the areas indicated in the questionnaire in the period of interest has to be considered and integrated in the method to assess SR exposure. We used data collected by the satellites of the European Space Agency, findable on the Tropospheric Emission Monitoring Internet Service (TEMIS) website. The first data available in TEMIS database is the UV index, valid for clear-sky conditions, that is an artificial quantity, derived from the UV irradiance at the ground level weighted by the International Commission on Illumination (Commission Internationale de l'Éclairage – CIE) action spectrum for the susceptibility of the caucasian skin to solar erythema. Clear sky UV index in TEMIS database has been available since November 1978 for many countries all over the world. Another more specific data available from TEMIS is the UV dose, derived from satellite observations, from sunrise to sunset, with a time step of 10 min. The UV dose takes into account the presence of clouds and estimates the daily amount of UV radiation absorbed by the human skin, expressed in kJ/m^2. Ultraviolet dose in TEMIS database has been available since 1995 for many countries all over the world.

Regarding the Italian environmental data, we reported in this paper the TEMIS UV doses referred to the year 2012 of Lampedusa, Rome and Venice, despite no subjects in our sample came from these 3 places. We chose these regions because they are continuously monitored by the European Space Agency for measuring the average daily environmental UV dose on a horizontal plan in cloudiness conditions and they may represent the typical theoretical environmental exposure of a person living and/or working and/or spending holidays respectively in the South of, Center of, and North Italy.

Collection of objective individual SR exposure data

To take into account individual factors (posture, adoption of protective habits, characteristics of the workplace, etc.), we have performed "on field" measures of personal SR exposure in outdoor workers. Following the experience of a relevant Italian regional project on the prevention of UV exposure for outdoor workers, in which the research sector of the National Institute for Insurance against Accidents at Work (INAIL) collaborated [25], 2 INAIL experts in optical radiation and industrial hygiene (A. Militello and M. Borra) collected measures of effective radiant exposure (H_{eff}) in a group of fishermen working on 3 fishing boats, different for dimension and protective equipment, sailing in the Italian Mediterranean sea in a region included between latitudes 41–43'N. The measurements were performed with polysulfone and electronic dosimeters positioned on the back, on the arm (to represent eye exposure according to Coroneo [26], too), on the chest and on the cap's peak of the fishermen as well as on the boat and on the wharf to measure the environmental exposure.

RESULTS

Subjective evaluation

We collected a total of 58 questionnaires in voluntary subjects aged 43–91 years old (mean age (M) = 70.8 ± standard deviation (SD) = 11 years), 81% male. With regards to occupation, 57% of the patients reported an outdoor activity as the main profession in their life, performed for an average of 31.3 years per person. No significant differences were observed between outdoor workers (OW) and indoor workers (IW) for the main socio-demographic and anamnestic characteristics investigated: age, sex, smoke habits, alcohol consumption, diabetes. The most frequent outdoor jobs were those in agriculture – 20.7% of the subjects, and the construction sector – 13.8%. Subjects reported to work outside for 4.4 h/day on average, between 9 a.m. and 5 p.m., 1.2 h between 11 a.m. and 3 p.m. Only 24% of the sample reported to often stay in the shades while they were working outside and 27% reported to often work next to reflecting surfaces. Outdoor workers did not refer to any adequate use of protective equipment to repair themselves from sunlight during the occupational activities (Table 2): 15.2% of OW never wore protective clothing, 90% never used sunscreens at work, 39% never wore a brimmed hat, 60.6% never used protective sunglasses.

Regarding leisure time, not considering vacations, the subjects reported outdoor activities for 3.7 h on average between 9 a.m. – 5 p.m., 0.8 h between 11 a.m. – 3 p.m. Eleven percent of the subjects reported to sometimes/often use tanning beds during their leisure time. Fifty-seven percent reported to perform an outdoor sport, for about 4.7 h per week on average and 18.4% reported to never/seldom stay in the shades during their outdoor leisure time. The Table 3 shows the individual protective habits reported by the subjects during their leisure time: 57.1% of the subjects wore only seldom adequately protective clothing, 60.7% never used sunscreens during their leisure time, 48.2% never wore a brimmed hat and 30.4% never used protective sunglasses.

With regard to vacation periods in summer season, the subjects reported to spend on average 19.6 days/year in vacation, staying outside on average for 5.1 h between 9 a.m. – 5 p.m., and 1.4 h between 11 a.m. – 3 p.m. Only 9.4% of the subjects reported to usually spend vacations in tropical or equatorial places. During the time outdoor, subjects reported to be close to reflecting water surfaces for 2.2 h on average. The 38.5% of the subjects reported often/always sunburns during their vacation periods, although the 54.3% reported to stay often in the shades. The Table 4 shows the individual protective

Table 2. Adoption of individual protective equipment at work among outdoor workers in Italy, 2012
Tabela 2. Stosowanie środków ochrony indywidualnej w czasie pracy na wolnym powietrzu we Włoszech w 2012 r.

Individual protective equipment Środek ochrony indywidualnej	Adoption of individual protective equipment Stosowanie środków ochrony indywidualnej [%]				
	never nigdy	seldom rzadko	sometimes czasami	often często	always zawsze
Protective clothing / Odzież ochronna	15.2	33.3	24.2	18.2	9.1
Sunscreen / Filtr przeciwsłoneczny	90.9	6.1	–	3.0	–
Hat / Nakrycie głowy	39.4	6.1	18.2	3.0	33.3
Sunglasses / Okulary przeciwsłoneczne	60.6	6.1	18.2	9.1	6.1

Table 3. Adoption of individual protective equipment during leisure time (not vacations) among outdoor workers in Italy, 2012
Tabela 3. Stosowanie środków ochrony indywidualnej w czasie wolnym (oprócz wakacji) przez robotników pracujących na wolnym powietrzu we Włoszech w 2012 r.

Individual protective equipment Środek ochrony indywidualnej	Adoption of individual protective equipment Stosowanie środków ochrony indywidualnej [%]				
	never nigdy	seldom rzadko	sometimes czasami	often często	always zawsze
Protective clothing / Odzież ochronna	7.1	57.1	14.3	16.1	5.4
Sunscreen / Filtr przeciwsłoneczny	60.7	23.2	8.9	5.4	1.8
Hat / Nakrycie głowy	48.2	19.6	8.9	12.5	10.7
Sunglasses / Okulary przeciwsłoneczne	30.4	25.0	14.3	16.1	14.3

Table 4. Adoption of individual protective equipment during vacation among outdoor workers in Italy, 2012
Tabela 4. Stosowanie środków ochrony indywidualnej w czasie wakacji przez robotników pracujących na wolnym powietrzu we Włoszech w 2012 r.

Individual protective equipment Środek ochrony indywidualnej	Adoption of individual protective equipment Stosowanie środków ochrony indywidualnej [%]				
	never nigdy	seldom rzadko	sometimes czasami	often często	always zawsze
Protective clothing / Odzież ochronna	69.8	15.1	9.4	5.7	–
Sunscreen / Filtr przeciwsłoneczny	24.5	20.8	22.6	22.7	9.4
Hat / Nakrycie głowy	54.7	7.5	7.5	17.0	13.2
Sunglasses / Okulary przeciwsłoneczne	36.5	11.5	11.6	19.2	21.2

equipment adopted by the subjects during their vacations: 69.8% of the subjects never wore protective clothing, 24.5% never used sunscreens during their vacation time, 54.7% never wore a brimmed hat and 36.5% never used protective sunglasses.

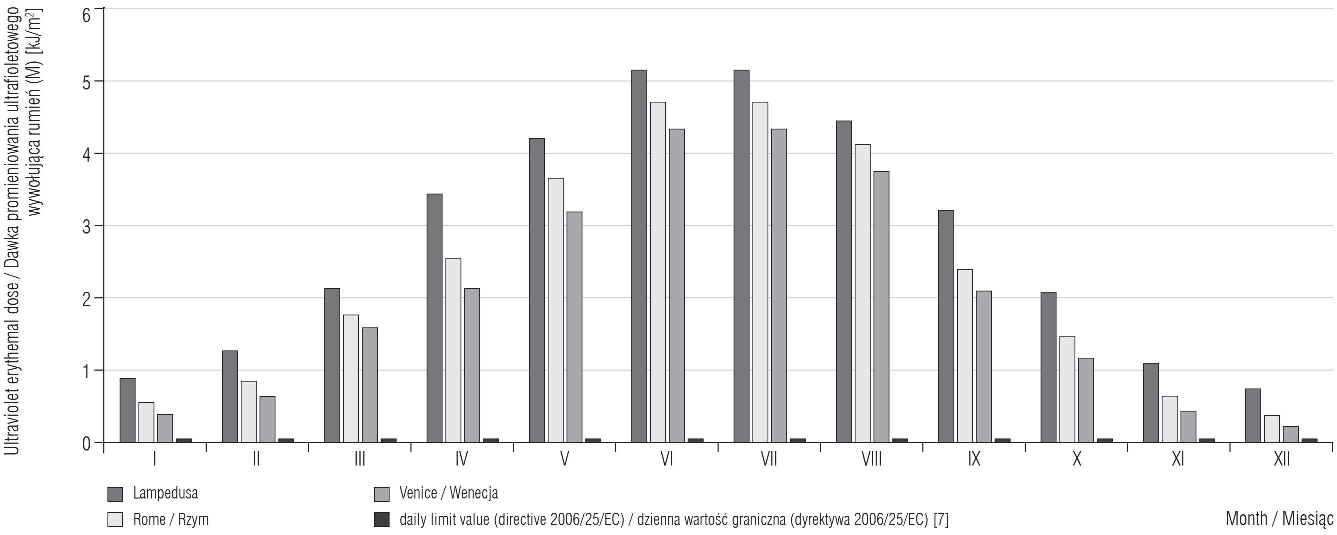
Objective evaluation

Environmental exposure data

In the Figure 1 we report the average daily UV dose registered during the year 2012 in three different places in Italy, representing the typical exposure respectively of Southern, Central and Northern Italy: Lampedusa – 35°30'N, Rome – 41°53'N, and Venice – 45°26'N. We found the most elevated exposure during June and July, with a daily UV erythemal dose ranging between 4.2 kJ/m^2 in Venice to 5.1 kJ/m^2 in Lampedusa. The lowest environmental exposure was found in January and December in Venice, with an average UV erythemal dose of 0.2 kJ/m^2.

Individual exposure data

The results of the on-field measures of effective radiant exposure in a small group of 6 fishermen are showed in the Table 5. The highest exposure to solar UVR has been measured for the nose, ear and the upper part of the fishermen's shoulders with the electronic dosimeter placed on the cap's peak of the outdoor workers, reaching an effective radiant energy of 0.9 kJ/m^2. The lowest measure of 0.04 kJ/m^2 was collected on the third boat (for further details on the measurements performed and on the characteristics of the fishermen, see also the paper published by 2 of the authors [27]).



M – mean / średnia.

Fig. 1. Daily ultraviolet erythemal dose in Italy, 2012
Ryc. 1. Dzienna dawka promieniowania ultrafioletowego wywołująca rumień we Włoszech w 2012 r.

Table 5. Relative ultraviolet dose on one working day in sunny weather – effective radiant energy (H_{eff}) for 6 fishermen in Italy, 2012
Tabela 5. Względna dawka promieniowania ultrafioletowego w ciągu słonecznego dnia – efektywna energia promieniowania (H_{eff}) u 6 rybaków we Włoszech w 2012 r.

Boat No. Nr łodzi	Ultraviolet dose Dawka promieniowania ultrafioletowego [kJ/m²] (M)			
	back plecy	cap's peak górna część czapki	external arm zewnętrzna powierzchnia ramienia	chest klatka piersiowa
1	0.44–0.68	0.75–0.90	–	0.28
2	0.15–0.34	0.40	–	–
3	0.04–0.17	–	0.05–0.12	0.15

M – mean / średnia.

DISCUSSION

The solar radiation exposure is a significant risk factor for the development of both acute and long term skin and eye diseases such as sunburns, photokeratitis, photoaging, actinic keratosis, pterygium, cataract, basal and squamous cell carcinomas and malignant melanoma. However, to date there are still some limitations in the current scientific knowledge, in particular regarding the association between specific characteristics of these diseases (histopathology, localizations, age of onset, etc.) and the cumulative occupational and non-occupational SR exposure. In addition, we still have not an adequate knowledge about the effectiveness of protective devices in preventing SR related diseases. Regarding protective habits, the pilot administration of the questionnaire developed for our research has shown a scanty adoption of protections in outdoor workers, in accordance with a previous Italian study conducted in a group of outdoor workers from Tuscany Region [25] where authors found that the clothing worn by workers was often inadequate as compared to the high level of exposure to UV.

As regards to environmental SR exposure in Italy, the collection of environmental data through the online database of the European Space Agency showed a much higher daily UV exposure at the Earth's surface as compared to the limit of 30 J/m² – effective radiant exposure (H_{eff}) – set in the European Directive 2006/25/EC for non-coherent artificial optical radiation with a wavelength of 180–400 nm (UVA, UVB and UVC) [7]. The average daily UV erythemal dose in all the months of 2012 was higher than 30 J/m² in all the three places considered, one in the North (Venice), one in the South (Lampedusa island) and one in the center of Italy (Rome), also in the Winter months. According to another Italian study conducted in Tuscany, in Spring workers received the 53–87% of the total amount of environmental SR on the back, and about 30–60% on the arms. During summer, outdoor workers received the 36–77% of ambient exposure on the back and 19–43% on the arms [19], respectively. The exposure of the external arm is relevant because, according to the "Coroneo's effect," it represents the exposure of the external part of the face and of the eye and it is important to evaluate the UVR dose coming from the side (oblique light) [26].

The environmental data collected also showed that the weight of the UV exposure during November, December, January and February was negligible as compared to the March–October period, supporting the choice of not considering the period November–February in the interviewer-administrated questionnaire, focusing only on the period March–October, that is the most relevant in determining the cumulative SR exposure. Winter months are considered in the questionnaire only in the case of winter vacations on the snow, that last at least 1 week per year.

By means of the pilot administration of the questionnaire in a group of voluntary subjects and on-field measurements in a small group of fishermen, we have collected data suggesting a high SR exposure for outdoor workers, and in particular farmers, construction and maritime workers. However, during the measurement campaign in the fishermen group, performed according to a preventive purpose [25,27], we could not be able to interview the workers with our ad hoc questionnaire: this factor is a relevant limitation for the current development of our methodology because at present we can't associate the questionnaire's answers to specific individual measurements.

Despite this limit, the occupational exposures suggested by our questionnaire or measured in the group of fishermen are in accordance with recent studies that have shown an exposure in terms of Standard Erythemal Dose (SED) of 9.9 SED in Australia [13], 11.9–28.6 SED in Switzerland [14], 6.11 SED in Spain [15] for the construction sector. It has to be noted that 1 SED is equivalent to an effective radiant exposure of 100 J/m^2 [2]. Regarding farmers, high exposure to SR has been reported in New Zeland [16], Australia [17], Austria [18], and also in Italy [19], where it has been collected to measure effective radiant exposure of 1870 J/m^2 in April. With regard to maritime workers, a Spanish study has measured a personal exposure of 1143 J/m^2 [20], higher than the maximum effective radiant exposure of 900 J/m^2 that we measured with a dosimeter placed on the top of the head of a fisherman working on a small boat with inadequate protective equipment (artisan fishery). Maritime workers have been investigated also in an Australian study and their exposure ranging from 1.7 to 6.9 SED [21].

In all the above cited studies researchers measured an acute exposure to SR by means of personal dosimeters on a single day or few days. In order to retrace the history of chronic exposure to SR in groups of outdoor workers, considering also leisure activities, we developed an algorithm that allows us to integrate subjective data from the questionnaire with objective climate data, to obtain an exposure index that esteems the cumulative SR exposure of a specific tissue. The equation 1 is an estimate of the average annual effective UV dose to a specific tissue (Eh) and it takes into account: the fraction of time (xi) the tissue (i) is actually exposed to SR; the average exposure ratio (yi) of the effective irradiance measured on the tissue is compared with the effective irradiance measured on the horizontal plane; the monthly coefficient (ei) multiplied by the average annual effective radiant exposure on a horizontal plane for the specific locality (Ea) to obtain the average monthly effective radiant exposure on a horizontal plane; the coefficient (ma) which takes into account the use of protective equipment (hats, sunglasses, sunscreen, etc.); the coefficient (na) which takes into account the presence of environmental factors that influence the exposure (canopies, awnings, vegetation, etc.).

$$\text{Eh (tissue)} = \sum_{i=1}^{12} \text{xi} \times \text{yi} \times \text{ei} \times \text{Ea} \times \text{ma} \times \text{na} \qquad (1)$$

For the determination of the coefficient (ma) which takes into account the use of protective equipment we use specific coefficients adapted from the previously discussed models of Rosenthal et al. and McCarty et al. [23,24]. For example, for a habitual use (according to the questionnaire answers "often" or "always" adopted) of normal clothing we have a coefficient of 0.2, for no use we have a value of 1. Regarding sunscreens, we have a coefficient of 0.3 for a regular use, 1 for no use. Regarding hat, we may have a large brimmed hat with a coefficient of 0.3 in the case of habitual use both for the neck and the forehead (and cheek, ear lobe, lower lip, underside chin), and a coefficient of 0.8 for the neck and 0.5 for the forehead and the other face and head regions in the case of habitual use of a large brimmed hat. In the case of use of sunglasses, we use coefficients for eye exposure: 0.99 if the protective equipment is never used, 0.78 if it is used seldom, 0.48 if it is used sometimes, 0.34 if it is often used and 0.13 if it is always used [23,24].

For the coefficient (na) in our algorithm, which takes into account the presence of environmental factors influencing the exposure, we use a "Sky View Factor," which is the fraction of the sky visible from a given observation point on the ground, taking into account the obstacles, natural or artificial, covering a variable part of the sky view, and we use also the specific Albedo coefficients for different surfaces to evaluate the reflecting phenomena [5], making an approximation based on the Likert scale of the questionnaire's answers (never = 0% of the period, seldom < 20%, sometimes < 40%, often = 60%, always = 100%).

Finally, regarding the posture, which was a major factor influencing back and chest exposure in our group of fishermen (if the worker bends down he or she shades his chest while at the same time he or she increases the exposure on the back), in order to determine the ratios of exposure in various parts of the human body during the execution of outdoor tasks, further on-field measurements of individual exposure are needed. These measurements are useful to calculate the reduction or multiplication coefficients of the SR that reaches specific parts of the body: our aim is to carry out several on-field measurements to characterize the type of exposure for various outdoor activities.

The effect of working posture in influencing SR exposure is also confirmed in a recent Swiss study on construction workers [14], in the case of which the authors have found that posture and orientation accounted for at least 38% of the total variance of relative individual exposure, accounting for more than the altitude on the total variance of effective daily exposures. In our algorithm, we use a coefficient related to the Anatomical

Region (AR) and it is the ratio between the irradiance on the horizontal plane and the irradiance on a given anatomical region. We consider the irradiance ratio for standing position at 45° of solar elevation angle, with different coefficients weighted on azimuth angle and posture prevalence [28,29].

CONCLUSIONS

Solar radiation exposure perpetrated for several years is typical of outdoor work and for an advancement in the knowledge of the epidemiology of SR related disease in the case of workers, a comprehensive evaluation of cumulative exposure is needed. We elaborated a new method to esteem the total lifelong individual exposure to SR and this tool could be useful to adequately evaluate the SR reaching specific target organs, like skin and eyes, taking into account both subjective and objective indicators of individual and environmental exposure as well as considering the influence of leisure activities.

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