Assessing the Cumulative Solar Radiation Exposure among Outdoor Workers: Presentation of a Method for Epidemiological Studies

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***Abstract* - So far, few studies on occupational risk related to Solar Radiation (SR) in outdoor workers have attempted to retrace a detailed history of individual exposure. We propose a new method for the evaluation of the SR cumulative exposure both during work and leisure time, integrating subjective and objective exposure data. The former are collected with a questionnaire, which investigates in detail work and leisure activities during life. The latter are available through internet databases for many geographical regions and provide an estimate of the SR on the Earth's surface in specific areas and periods. These data will be integrated in a mathematical model, in order to obtain an esteem of the individual total amount of SR the subjects have been exposed to during their life. This personal exposure index can be used to evaluate specific correlations with the biological effects and to weigh the role of the personal and environmental factors that can increase or reduce SR exposure.**

I. INTRODUCTION

The health risk related to an excessive exposure to solar radiation (SR) is well known [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. The UV radiation (UVR) is further divided into UV-A (wavelength 380-315 nm), UV-B (315-280 nm) and UV-C (280 - 100 nm), while the infrared into IR-A (1400-780 nm), IR -B (3000 - 1400 nm) and IR-C (1 mm - 3000 nm) [2]. 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 UVR by various gaseous components, in particular the ozone, which blocks all wavelengths of less than 290 nm , and so all the UV-C and a significant part of the UV- B. 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 [3].

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 IARC as human carcinogens, group I [1, 4].

According to recent studies, outdoor workers have a relevant exposure to SR and the exposure levels largely exceed the limit of 30 Joule / m^2, effective radiant exposure (H_{eff}) referred to a daily exposure of 8 hours. This limit was set in the European Directive 2006/25/EC to prevent the adverse effects of non-coherent artificial optical radiation with a wave-length of 180-400 nm (UVA, UVB and UVC) [5-7].

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 show that UVR is a carcinogen in 36 employment sectors of the European Union and for 11 of these ranks first among the other carcinogens [8].

The highest exposure to UVR have been registered among farmers, construction and maritime workers [8]. For example, regarding construction workers, recent studies have showed that they are exposed to SR with a Standard Erythemal Dose (SED) of 9.9 in Australia [9]; they have a daily dose ranging from 11.9 to 28.6 SED depending on the altitude in Switzerland [10] and they are exposed to 6.11 SED in Spain [11].

For farmers, high exposure to UVR have been reported in New Zeland [12], Australia [13], Austria [14], and also in Italy, where it has been collected a measure of 1870 Joule / m^2 in April [15].

With regard to other outdoor workers, a Spanish study have measured a personal exposure dose of 413 and 1143 Joule / square meter respectively in a group of gardeners and lifeguards [16]. Lifeguards have been investigated also in an Australian study and their exposure ranged from 6.9 to 1.7 SED [17].

In all these studies the researchers measured an acute exposure to SR in a single day or few days with personal dosimeters.

On the contrary, very few studies attempted to retrace the history of a chronic exposure to SR in groups of outdoor workers. Rosenthal et al presented a model of ocular and facial skin exposure to UVB that combines interview histories of work and leisure activities, eyeglass wearing and hat use with field and laboratory measurements of UV radiant exposure in a group of American watermen [18]. In Australia, McCarty et al. developed a simplified model for quantifying lifetime ocular UV-B exposure considering the ambient UV-B levels, the duration of outdoor exposure, the proportion of ambient UV-B that reaches the eye and the use of ocular protection [19].

These kind of methods are important because many individual and environmental factors can modify SR exposure and therefore influence the dose of SR that determines the pathological effects. To date there is no adequate knowledge on the interaction among these factors and the occurrence of adverse effects (especially the chronic ones).

The quality and quantity of SR that reach the Earth's surface vary with the elevation angle of the Sun above the horizon, so the exposure can 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 can absorb it and thus they can cause a reduction of the exposure, but they can also redirect UV rays with different mechanisms, like refraction, diffusion and reflection. Finally, the type of surface can increase SR exposure, for example fresh snow reflects up to 90% of UV rays [3].

In addition, there are also several individual factors that can 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. Other important aspects are individual protecting behaviours, such as the regular use of covering clothes, sunglasses and 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 on summer vacation's periods [3], [7].

Finally, one of the most important factor that influence skin exposure to SR are individual characteristics. People with fair photo-types, such as Fitzpatrick's photo-types I and II, are more sensitive to the UV damage [20].

As previously mentioned, sunlight exposure may cause several acute and chronic effects, mainly ocular and cutaneous, but also immunological and various others. According to a recent WHO review, acute ocular effects with a strong evidence of causality are photokeratitis, photoconjunctivitis and solar retinopathy; chronic diseases are pterygium, cortical cataract and epithelial cancers of the cornea and conjunctiva [1]. Several studies have reported high rates of pterygium and cataract in groups of outdoor workers [21], [22]. Cataract in particular is one of the most important eye diseases worldwide: WHO data show that there are about 161 million people worldwide affected by visual impairment, and cataract is the main responsible factor, being implied in the 47.8% of all the cases [23].

Regarding the skin, acute effects with strong evidence of causality are sunburns and photodermatoses; chronic effects are photoageing and solar keratoses, and skin cancers: Basal Cell Carcinoma (BCC), Squamous Cell Carcinoma (SCC) and Malignant Melanoma (MM) [1].

Each year in Europe there are approximately 2,000,000 diagnoses of epithelial skin cancer (BCC + SCC) [24].

Regarding MM, worldwide, every year 102,000 new cases (26,000 deaths / year) in men and 98,000 new cases (21,000 deaths / year) in women are recorded [25].

Epithelial skin cancers, and in particular BCC, are the most common among all the malignant tumors diagnosed every year in the European population. Several studies have investigated the association between occupational exposure to SR and the occurrence of skin cancers. In a recent German study, outdoor workers showed a relative risk (RR) for BCC of 2.9 (95% Confidence Interval – CI 2.2-3.9) and 2.5 (95 % CI 1.4-4.7) for SCC [26]. In the multicenter European study HELIOS, the construction sector showed an Odds Ratio (OR) for epithelial skin cancers of 1.10 (95 % CI 0.93-1.31) and the agriculture and fisheries sectors showed an OR of 1.18 (95% CI 0.96-1.45) [27].

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].

Finally, it has to be noted that SR exposure may also induce positive effects for human health: sunlight has got a key role in the metabolism of vitamin D and therefore in the prevention of diseases such as rickets, osteomalacia and osteoporosis [1].

In future epidemiological studies, a more accurate methodology for assessing occupational and environmental exposure to SR should be useful, in order to allow a better comparison between exposure levels and early biological skin and eye effects, and to study the role of the protective factors in the onset of these diseases.

II. METHODS

We are developing a tool for the evaluation of the cumulative lifetime exposure to SR both during working and leisure time, that integrates subjective and objective data.

Subjective data are collected with an interviewer-administrated questionnaire that assesses exposure modes during work and leisure activities (tab. 1).

The questionnaire is composed by three sections. The items of the questionnaire have been elaborated by a team of occupational physicians and experts in optical radiation and industrial hygiene.

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 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 with 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 first section of the questionnaire investigates outdoor work and it is composed by 18 items. A new copy of the section – henceforth "tab" – is administered in the following circumstances:

- job change (i.e. farmer, construction worker, quarryman, fisherman, forester, seaman, etc);
- workplace change, when it is supposed that there is a significant change in the SR exposure – different UV index;
- work tasks change (for the same job, we can have different tasks with different position adopted during

work, different number of hours in the sunlight and different protective equipment).

TABLE I: MAIN POINTS ASSESSED IN THE QUESTIONNAIRE TO EVALUATE SOLAR RADIATION EXPOSURE

Working time exposure	Leisure time exposure (not vacation)	Vacation exposure
1. Type of outdoor job	1. Place of residence (latitude)	1. Place of vacation (latitude)
2. Job place	2. Place of residence (altitude)	2. Place of vacation (altitude)
3. Working hours from 9 am to 5 pm	3. Outdoor hours from 9 am to 5 pm	3. Days of vacation per year
4. Working hours from 11 am to 3 pm	4. Outdoor hours from 11 am to 3 pm	4. Time spent outdoor during vacation
5. Lunch time	5. Practice of outdoor sports	5. Frequency of sunburns
6. Lunch place	6. Hours per week of outdoor sport	6. Use of suntan lotion
7. Prevalent posture at work	7. Exposure to UV lamps	7. Type of suntan lotion
8. Possibility to shelter from the Sun at work	8. Exposure to UV lamps - years	
9. Presence of reflecting surfaces	9. Exposure to UV lamps – treatments per week	
10. Type of reflecting surfaces		8. Presence of water/ snow.
11. Working time near reflecting surfaces	10. Time near reflecting surfaces	9. Vacation time near water / snow
12. Working time with hat	11. Time with hat	10. Vacation time with hat
13. Working time with sunglasses	12. Time with sunglasses	11. Vacation time with sunglasses
14. Use of sunglasses with a specific protection	13. Use of sunglasses with a specific protection	12. Use of sunglasses with a specific protection
15. Working time with spectacles	14. Time with spectacles	13. Vacation time with spectacles
16. Working time with contact lenses	15. Time with contact lenses	14. Vacation time with contact lenses
17. Working time with protective clothes	16. Time with protective clothes	15. Vacation time with protective clothes
18. Working time with sunscreen protections	17. Time with sunscreen protections	16. Vacation time with sunscreen protections

The second section of the questionnaire investigates leisure outdoor activities and it is composed by 17 items. A new tab has to be administered when there is:

- residence change, when it is supposed that there is a significant change in the SR exposure – 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 (i.e. a new outdoor activity, such as a new hobby or outdoor sport);
- protective habits change (i.e. the respondent states that he has started to use sunglasses, hat, sunscreen protections, etc).

The third section of the questionnaire investigates leisure outdoor activities during vacation periods and it is composed by 16 items. If the vacation is spent on the snow the respondents have to consider also the winter months. A new tab has to be administered in the following cases:

- vacation place change, when it is supposed that there is a significant change in the SR exposure – 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 (i.e. the respondent states that he has started to use sunglasses, hat, sunscreen protection, etc).

To evaluate the feasibility of the questionnaire, a pilot administration was performed by one of the Authors (A.M.) in a sample of patients undergoing to a skin examination in an Italian dermatologic center between 01/16/2014 and 01/30/2014. Test reliability was evaluated using the Cronbach-Alpha [28]. At the end of each administration, the patient was asked to rate the comprehensibility and the utility of the three sections on a 5 point Likert scale and to write down suggestions and items not fully understandable, if any.

The second part of the method includes the collecting of objective data, and in particular climate data of the areas indicated in the questionnaire in the period of interest.

These data are available through internet databases for many geographical regions and they provide an estimate of the SR to the Earth's surface. As an example the Tropospheric Emission Monitoring Internet Service (TEMIS) spreads data collected by the satellites of the European Space Agency (ESA) [29]. The first data available is the clear sky UV index, that is the effective UV irradiance (1 unit equals 25 mW / m^2) reaching the Earth’s surface. It is based on the CIE action spectrum for the susceptibility of the caucasian skin to sunburn (erithema) and it is valid for cloud-free conditions at local solar noon. Clear sky UV index in this database is available since November 1978. Another more specific data available from TEMIS is the UV dose, that is an integration of the erythemal UV index, as derived from satellite observations, from sunrise to sunset, with a time step of 10 minutes. The integration takes the cloud cover into account, and thus leads to an estimate of the daily erythemal UV dose. UV dose in this database is available since 1995.

In figure 1 there is an example of the average daily erythemal dose registered during the year 2012 in three different regions 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 (fig. 1). The data reveal a much higher daily UV dose at the Earth’s surface compared to the limits set in the European Directive 2006/25/EC in all of these three places. The chart shows also that the weight of UV doses during November, December, January and February is negligible compared to the

March-October period, supporting the choice of not considering November-February in the questionnaire.

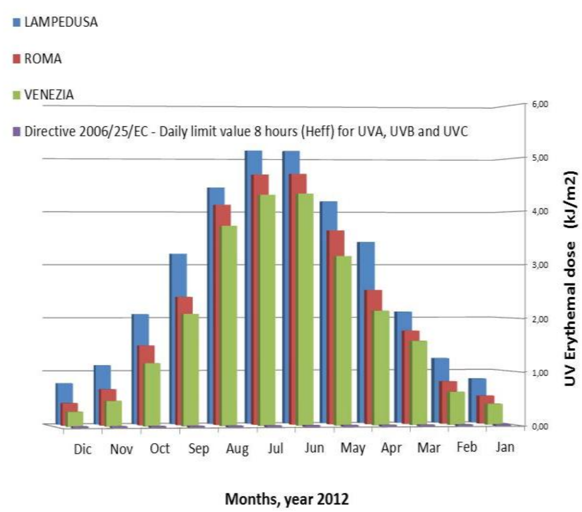

Fig. 1. Comparison of the average daily erythemal dose among three Italian regions during the year 2012

To validate the method taking into consideration environmental and individual factors (posture, etc.), we have done some "on field" measures of personal SR exposure. The results are useful to calculate the reduction- or multiplication-coefficients of the SR exposure that reaches specific parts of the body depending on the posture and on the personal habits adopted.

Two experts in optical radiation and industrial hygiene have collected several measures of effective radiant exposure (H_{eff}) in a group of 6 fishermen working on 3 boats in different places in Italy. The measures has been taken with polysulfon and electronic dosimeters positioned on the back, on the arm, on the chest and on the cap's peak of the fishermen and also on the boat and on the wharf to measure the environmental exposure.

Therefore, the data collected have been elaborated to determine the ratios of exposure in various parts of the human body during the execution of the fishermen tasks.

III. RESULTS AND DISCUSSION

The questionnaire has been administered to 9 patients that underwent dermatologic examination or therapy in an Italian hospital. The administration of the questionnaire has taken 25-40 minutes. The respondents are 6 men and 3 women aged between 46 and 80 (mean 61,7). Among these, 6 are affected by skin diseases related to SR exposure and they underwent both a control visit and a treatment of photodynamic therapy (PDT). The other 3 patients underwent only the dermatologic examination of the nevi, since they have familiarity for skin cancer. Among the patients with skin diseases, 3 have multiple BCC, 2 have multiple SCC and 3 have multiple actinic keratosis. All of them have lesions in various parts of the body: nape, front, chest, arm, back, forearm, thigh, nose and ear.

We administered a total of 16 tabs for the outdoor work section, with a value of Cronbach's Alpha equals to 0.86. Among the 9 respondents, 5 have been engaged in an outdoor job at least for six months as farmer, breeder, construction worker, Navy soldier, forester, dustman and electrician. The respondents have worked outdoor for 2 up to 36 years. Workers spend outside an average 5h 20' per day between 9 am and 5 pm and 1h40' between 11 am and 3 pm. They almost never (mean value for item 5= 1.2) have launch outside and they are for about the 25% of their working day in a shelter and for another 25% next to a reflecting surface (mean score of items 8 and 11 respectively = 1.9 and 2.0). Outdoor workers use hat and protecting clothes for about the 75% of the working hours (mean score = 4.0 and 3.6 respectively), but they use sunglasses and sunscreen protection only for the 10 % of their working time (mean score of the items 13 and 18 respectively = 1.4 and 1.3).

For the section that investigates leisure activities, we have administered a total of 16 tabs with a Cronbach's Alpha of 0.56. The coefficient rises to 0.68 if the item 8 that investigates the number of years in treatment with UV lamps is deleted.

The respondents declare that they spend outdoor an average time of 3h 50' between 9 am and 5 pm and 1h10' between 11 am and 3 pm. They are almost never near reflecting surfaces (score of the item 10 = 1.4). They wear sunglasses and hat for about the 30% of their time outdoor (mean score of the items 11 and 12 = 2.3 and 2.4 respectively), they wear protective clothes for half the time (mean score of items 16 = 3.0) and they use sunscreen protections only for the 10 % of the time spent outdoor (mean score of item 17 = 1.5). The practice of an outdoor sport is referred by 5 respondents with an average of 8 hours of sport per week. 2 people declare they have regularly taken UV lamps sunbath for many years.

For the section investigating the vacation periods, we have administered a total of 46 tabs with a Cronbach's Alpha of 0,3. After the deletion of 3 items the Cronbach's alpha rised to 0.62. We deleted the item 'hours outdoor per day', which has an average value of 7h 10' that so in the vacation period this variable may be considered always with its maximum value. The other 2 removed variables are the items that investigate the use of spectacles and contact lenses during vacation, because in this small sample nobody has significant visual problems and they are not used to wear glasses nor contact lenses. During the time spent outdoor, the respondents declare they are next to reflecting surfaces (almost always sea water, only in one case snow) for half the time (mean score of item 9 = 2.9). With regard to the protective habits during the vacation periods the respondents declare they use sunglasses and hat for about the 70 % of the time spent outdoor (mean score of items 10 and 11 = 3.9 and 3.4 respectively); they use sunscreen protections for the 30% of the time (mean score of item 16 = 2.3) and protective clothes only for the 15 % (mean score of item 15 = 1.7).

5 subjects rated the comprehensibility and the utility of the questionnaire proposed. All of them gave to all the sections a high score both in comprehensibility and in utility. The outdoor work section received an average rating of 4.8 in comprehensibility and 4.6 in utility. The leisure time section

has been rated 4.6 both in comprehensibility and in utility. Finally, the vacation section has been rated 4.4 in comprehensibility and 4.6 in utility. No one wrote down suggestions or indicated problems in the formulation of the items.

The results of the questionnaire show a good reliability for the section that investigates outdoor work and a quite good Cronbach's Alpha for the section investigating leisure activities, after the removal of one item. The vacation section may has also a sufficient reliability after the removal of 3 items. We need to enlarge this preliminary sample in order to better understand which are the items that affect the reliability of the questionnaire and then to implement the solutions.

The results of the on-field measures of effective radiant exposure in a small group of fishermen are showed in table II.

TABLE II: AVERAGE RELATIVE UV DOSE IN kJ / m^2 - EFFECTIVE RADIANT ENERGY (H*eff*) - FOR FOUR DIFFERENT PARTS OF THE HUMAN BODY IN 6 FISHERMEN (ONE WORKING DAY, SUNNY WEATHER)

	Back	Cap's peak	External arm	Chest
First boat	0.44 - 0.68	0.75 - 0.90	/	0.28
Second boat	0.15 - 0.34	0.4	/	/
Third boat	0.04 - 0.17	/	0.05 - 0.12	0.15

The highest exposure to solar UVR have been measured for the nose, ear and upper shoulder of the fishermen with a dosimeter placed on the cap's peak of the men. This information is important both to understand which are the parts of the body with a higher exposure and to evaluate the protective role of wearing hat in reducing SR exposure. Working posture is a major factor influencing back and chest exposure: if the worker bends down he shades his chest while at the same time he increases the exposure on the back. Finally, the dosimeter placed on the external arm, due to the "Coroneo's effect", 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) [30].

These measures seems to be appropriate to characterize the relationships between working postures, protective equipment and reflecting / refracting phenomena and the exposure of different parts of the body. These measures should be carried out for different outdoor jobs, to finally elaborate specific coefficients for the factors modulating SR exposure.

This approach will allow 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 (1).

$$E_h(tissue) = \sum_{i=1}^{12} x_i * y_i * e_i * E_a * m_a * n_a \qquad (1)$$

The equation (1) is an estimate of the average annual effective UV dose to a specific tissue (E_h) and it takes into account: the fraction of time (x_i) the tissue i is actually exposed to SR; the average exposure ratio (y_i) of the effective irradiance measured on the tissue i compared with the effective irradiance measured on the horizontal plane; the monthly coefficient (e_i) multiplied by the average annual effective radiant exposure on a horizontal plane for the specific locality (E_a) to obtain the average monthly effective radiant exposure on a horizontal plane; the attenuation coefficient (m_a) which takes into account the use of protective equipment (hats, sunglasses, sunscreen, etc); the attenuation coefficient (n_a) which takes into account the presence of environmental factors that moderate the exposure (canopies, awnings, vegetation, etc.).

The final index enable to esteem the total lifelong individual exposure to SR of the subjects, and could be a useful tool to be applied in future epidemiological studies on the effects of SR, and their prevention.

IV. Conclusion

The proposed instrument is aimed to provide a detailed estimate of lifetime exposure to SR in groups of outdoor workers, taking into account individual factors such as the use of sunglasses and protective clothing, prevalent postures during work, etc. These data, integrated with long term climate data, enhable the calculation of a semi-quantitative assessment of the cumulative dose of SR to the ocular surface and to various skin areas.

This method is innovative since at present a few studies in the scientific literature have attempted to retrace a detailed history of SR exposure, and it should also overcome studies based on short term instrumental measurement of radiant energy.

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