POLYSULPHONE DOSIMETRY: A TOOL FOR PERSONAL EXPOSURE STUDIES

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ABSTRACT

This work presents and compares the results of two in-field experiments with the aim of assessing ultraviolet exposure in typical leisure and working environments characterized by enhanced ambient *UV* radiation levels. The in-field campaigns were carried out in a mountainous area of northern Italy (Valle d'Aosta) and on the beach of a popular sea-side location in central Italy (Fregene), involving volunteering skiers and sunbathers respectively. Polysulphone dosimetry was used to determine personal doses.
The study also proposes a statistical methodology for the data analysis, taking into account additional data such as skin colorimetric parameters (luminance, redness and yellowness), skin temperature and other ancillary information gathered during the experiments.

KEY WORDS: *UV radiation, personal dose, polysulphone dosimetry*

1. INTRODUCTION

Solar ultraviolet radiation (*UVR*) has influenced the evolution of terrestrial life, conditioning the passage of living organisms from water to the Earth's surface subsequently to the origination of the stratospheric ozone layer. The exposure of humans to solar *UVR* induced different skin pigmentation: darker for people at low latitudes for protection from harmful effects (acute or long-term damages to the eyes and skin); fair for those at higher latitudes to maximize the beneficial effects (cutaneous synthesis of vitamin D [Holick, 2000]). Changes in habits and attitudes and the increase in human migration from original areas has meant that many people all over the globe are now exposed to more, or less, solar *UVR* than in the past. In addition to this, in a future scenario of higher ambient temperatures due the global warming [Norval et al, 2007], people living at mid-latitudes might spend more time outdoors.

Melanoma skin cancer (*MSC*) and non melanoma skin cancer (*NMSC* such as squamous cell carcinoma, *SCC*, and basal cell carcinoma, *BCC*), are the most common types of cancer among fair-skinned populations [Leiter and Garbe, 2008]. In the last centuries there has been an increase of skin cancer in white people who have migrated to low latitudes (i.e. Australia) and a rise of rickets and osteomalacia in dark-skinned populations living at high latitudes [WHO, 2006]. *MSC* are very rare during childhood and youth, more frequent between 30 and 60 years. A global estimate of new cases is around 100000 every year. An approximate estimate for Italy is of 7000 new cases every

year. In the past five years, 4000 deaths among males (5 per 100000 inhabitants) and 3000 among females (6 per 100000 inhabitants) have been recorded, with peaks of 10 out of 100000 in Trieste, 6-7 in Genova, Veneto and Emilia Romagna [Epicentro, 2008]. The incidence of *MSC* between 1980 and 2000 increased by 4-8% per year. *SCC* and *BCC* also increased during the last years. *BCC* are 50 times more frequent than *MSC* and affect young people between 25 and 30 years, too. Moreover, the well documented significant decrease in total ozone observed since the 1970s onwards, should lead to an increase of solar ultraviolet radiation B (*UVB*, 290-320 nm) reaching the Earth's surface, even though the influence of cloud cover and atmospheric pollution on *UVR* is not yet well understood [Parisi, 2005]. If ambient *UVR* (the *UV* radiation on a horizontal surface) enhances, in the absence of changes in personal attitudes and sun protection habits, the *UVR* overexposure can result in health diseases observed principally in the skin, the eyes and the immunological system [Diffey, 2004]. Besides the adverse effects, solar *UV* radiation is also responsible of vitamin D synthesis required for skeletal health. In addition various authors have suggested that low vitamin D can be considered a risk factor for breast, prostate and colon cancers [Grant, 2002; Chen and Holick, 2003; Grant and Holick, 2005]. The scientific debate is still ongoing regarding the health duality aspect of *UVR* and the determination of the optimal ambient *UVR* exposure. For such reasons, the quantification of the personal doses (*PD*) on different body parts and the search for biological indicators can help to define the proper level of *UV* exposure [Webb and Engelsen, 2006; Grant and Holick, 2005].

Polysulphone (*PS*) dosimetry is a widely tested methodology for reliable quantification of the erythemally effective *UV* dose received by an anatomical site [Davis et al, 1976; Diffey, 1984]. The Exposure Ratio (*ER*) for a specific body site, that is the ratio between the erythemally weighted personal dose measured by the *PS* dosimeter and the corresponding ambient dose on a horizontal plane measured by a radiometer [Webb, 1998], can be used to characterize *UV* exposure for photobiological studies. Results, in terms of *ER*, of two field experiments carried out in the mountainous areas of Italy and on the beach of a popular sea-side location in central Italy, involving volunteering skiers and sunbathers respectively, are presented and discussed. Moreover, the study proposes a statistical methodology for the data analysis, taking also into account skin colorimetric parameters (L^*, luminance; a^*, redness; b^*, yellowness), skin temperature (T_s) and additional information (such as the amount of free radicals, *FR*, in the plasma) collected during the experiments.

2. BASIC QUANTITIES AND DEFINITIONS

The Sun's spectrum can be approximated with that emitted by a black body at about 5800 K [Parisi, 2005], that is the temperature of the solar outer layers. About 9% of the solar extraterrestrial radiation is in the *UVR* range. Solar *UVR* can be divided in [Webb, 1998]: *UVC* (200-290 nm), *UVB* (290-320 nm) and *UVA* (320-290 nm). *UVC* is totally absorbed by oxygen, ozone and trace species; more than 90% of *UVB* is absorbed by atmospheric ozone; *UVA* is weakly affected by ozone and other atmospheric constituents. Thus the portion of solar *UVR,* from human health point of view, consists of *UVA* and *UVB*. An example of spectrum in a summer day with clear sky conditions measured at the latitude of 42°N is shown in Figure 1.

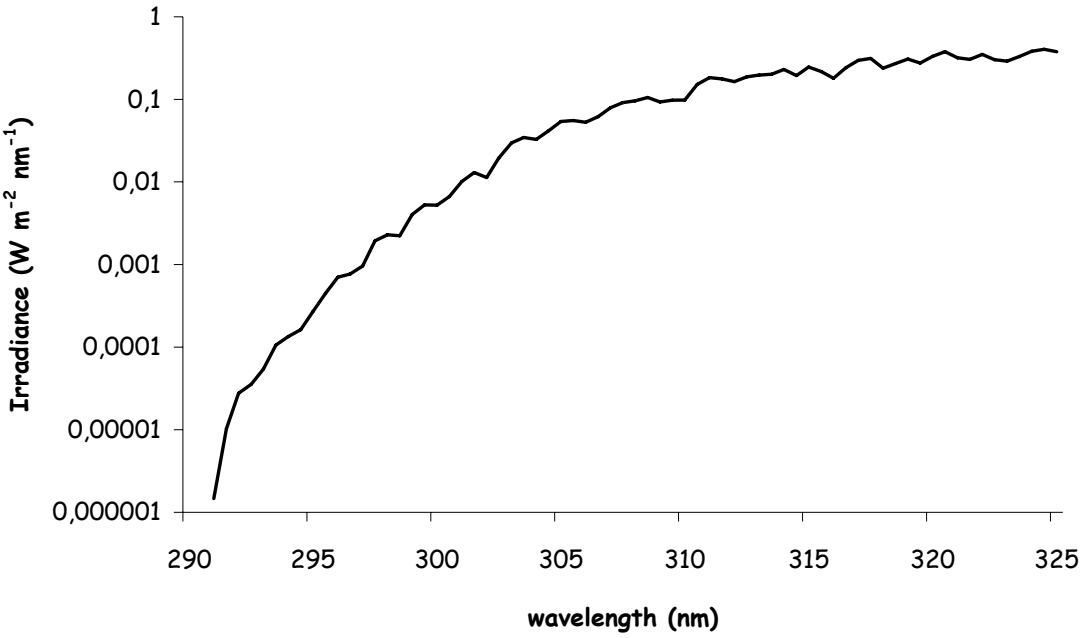

Figure 1: Spectrum of solar irradiance between 290 and 325 nm measured at a latitude of 42°N on a clear-sky day (22 July 2001). The vertical scale is logarithmic.

Solar *UVR* reaching the Earth's surface is measured continuously by ground-based instruments (spectroradiometers and/or broad-, moderate- or narrow-band radiometers: see section 4.1). Such instruments measure the quantity called irradiance (*I*), the flux density received by a horizontal surface and expressed in watt per square meter, Wm^{-2}. Solar ultraviolet irradiance is determined by integrating the spectral irradiance I_λ over the wavelength range 200-400 nm:

$$I = \int I_\lambda \, d\lambda \qquad [1]$$

If we are interested in a given biological effect, we have to use the action spectrum (*S*), representing the sensitivity of the living being to the incident radiation [Caldwell et al., 1986; Setlow, 1993]. In this work, the erythemal action spectrum [C.I.E., 1987] was used as the weighting function which simulates the damage process occurring in the skin. The ambient dose rate (*DR*) is obtained by multiplying the surface spectral irradiance with the action spectrum and then integrating over the range 200- 400 nm:

$$DR = \int I_\lambda S_\lambda \, d\lambda \qquad [2]$$

The units are Wm^{-2} (or $W_{eff}m^{-2}$ according to several authors, where "eff" stands for "effective"). *DR* depends on the Sun's position (through the solar zenith angle, *SZA*), the atmospheric attenuation (mainly due to atmospheric total ozone, clouds, aerosols), and surface albedo (normally less than 10%, except gypsum sand, which reflects about 15–30%, and snow, which can reflect up to 90%); altitude [Kerr, 2003]. The solar *UV* index (*UVI*) is an adimensional quantity, calculated multiplying *DR* by 40 [Cost-713, 2000]. *UVI* is widely used by several international weather services and the mass media as public information of *UV* radiation levels at the Earth's surface.

Figure 2 shows the climatological *UVI* values from 1992 to 2004 in Rome (middle latitudes urban site). Maximum values tend to occur during summer and do not usually exceed the *UV* Index value of 8. The upper and lower limits determined as standard deviation are also reported.

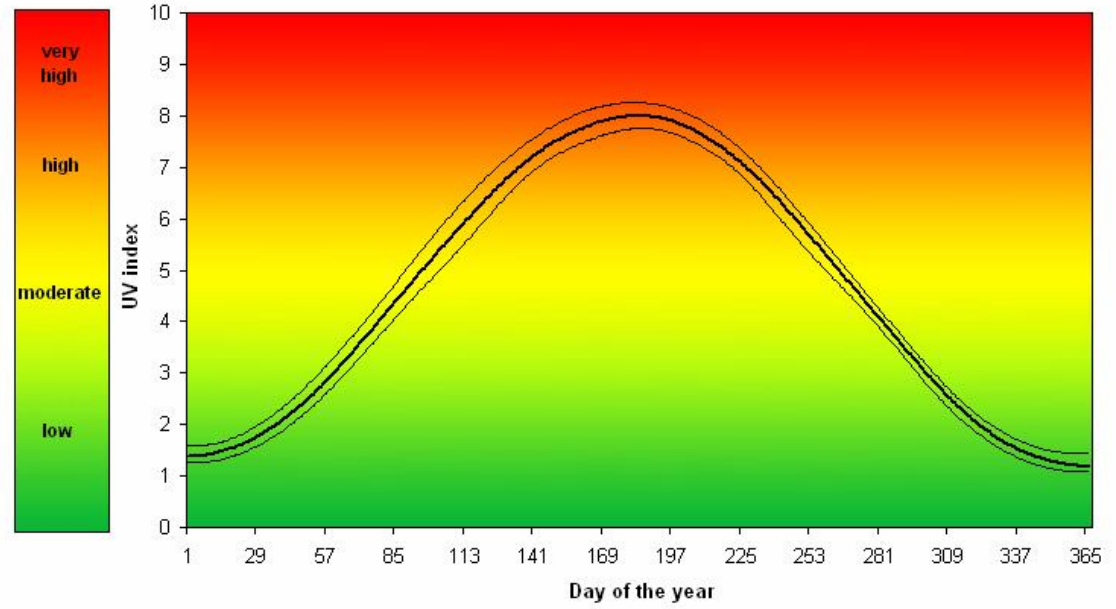

Figure 2: Climatological UVI Index at Rome (data from 1992 to 2004). Blue line is the climatolological reference for each day of the year, while the upper and lower black lines are determined as standard deviation of the data used for each daily climatological value

The integration of dose rate over a specified period of time (hourly, daily, weekly, monthly, yearly or other) yields the ambient dose (*AD* in Jm^{-2}):

$$\mathbf{AD} = \int \mathbf{DR}dt \qquad [3]$$

What happens when solar radiation hits a human being? Personal exposure (*PE*) is defined as the total amount of *UV* radiation reaching the body. Studies have shown that *PE* varies between 5% to 15% of the corresponding *AD*, with the exception of outdoor workers whose exposures can reach 20-30% [Wright and Reeder, 2005; Chodick et al., 2008]. Personal dose (*PD)* is related to the actual exposure of a defined body portion which is a variously oriented surface. It can be obtained using physical, chemical or biological dosimeters. The most widely used *UV* dosimeters are polysulphone (*PS*) films which have a response to *UV* radiation similar to human skin [Diffey, 1989; Kimlin, 2003] and can be a valid alternative also to those methodologies traditionally used in epidemiology [Chodick et al., 2008]. In the following we made use of the Exposure Ratio (*ER*), defined as the ratio between *PD* on a selected anatomical site and the corresponding *AD*, that is:

$$\mathbf{ER} = \frac{\mathbf{PD}}{\mathbf{AD}} \qquad [4]$$

ER is an adimensional quantity providing the percentage of *AD* received by the anatomical location. It is slightly dependent on the environmental exposure conditions accentuating individual habits and posture during exposure and allows to compare different exposure conditions and periods [Antoine et al., 2007].

3. ANCILLARY QUANTITIES AND DEFINITIONS

Human skin has two major components: the outer cellular epidermis (approximately 100–150 mm) and the inner largely non-cellular dermis (approximately 2–4 mm), separated by a membrane. The DNA Optical radiation incident on the skin may be reflected at the skin surface (between 4% and 7%), absorbed in the epidermis or dermis, scattered by cell organelles in the epidermis or collagen in the dermis and transmitted to deeper tissues. UVA penetrates the human skin more deeply than UVB. The properties of the skin surface can be altered by the application of topical agents, that can selectively increase or decrease radiation to critical targets in the epidermis. Ancillary measurements of biological markers in dosimetry studies can be useful to assess individual responses, if any, to UV exposure.

Skin colour can be determined by physical measurement of reflected visible light, expressed through the L*a*b* system defined by the Commission Internationale de l'Eclairage [C.I.E., 1986]. L* (luminance) gives the relative brightness on a scale from 0 (black) to 100 (white); a* (redness) represents the balance between red (positive value) and green (negative value) on a scale from +60 to -60; b* (yellowness) measures the colour saturation between yellow (positive value) and blue (negative value) on a scale from +60 to –60. Alaluf et al. [2002] found that colorimetric parameters of human skin depend on the ethnic skin types and the photoexposure of the anatomical site. The most common classification of skin types to UVR sensitivity is given by the Fitzpatrick scale [Fitzpatrick et al., 1974], based on the observation of hair and eye colours, skin pigmentation, burning and tanning tendency (Table 1).

Table 1: Fitzpatrick classification type [Fitzpatrick et al., 1974]

Skin Type	Skin Color	Characteristics
I	White; very fair; red or blond hair; blue eyes; freckles	Always burns, never tans
II	White; fair; red or blond hair; blue, hazel, or green eyes	Usually burns, tans with difficulty
III	Cream white; fair with any eye or hair color; very common	Sometimes mild burn, gradually tans
IV	Brown; typical Mediterranean caucasian skin	Rarely burns, tans with ease
V	Dark Brown; mid-eastern skin types	Very rarely burns, tans very easily
VI	Black	Never burns, tans very easily

The colorimetric scale *L*,a*,b** shows a poor ability to properly classify the intermediate phototypes II and III [WHO, 2006], so the visual classification is still a largely accepted method.
In order to distinguish the effects due to solar *UVR* on human skin and that due to the heat generated by *IR* radiation or other causes, measures of skin temperature (T_s) were taken during the experiments with volunteers. In this work skin temperature is used for the first time as a biological indicator in the dosimetric study

Free radicals (*FR*) are oxidant substances (reactive oxygen species, *ROS*) normally produced during metabolism and strictly controlled by anti-oxidant molecules. In healthy people there is a good balance between *FR* and anti-oxidants. Thus, *FR* measure could identify subjects with a high level of oxidative stress or show the effect of any treatment (i.e. anthistamines) or additive stress (i.e.

smoking). *FR* in the blood were here analyzed because of their possible role in ultraviolet carcinogenesis [Black, 2004].
The following ancillary information was included in the dosimetric study such as *sex, age*, *sunscreen use, habits,* recorded through questionnaires or personal diaries.

4. MATERIALS

4.1 Radiometers

The radiometers used in the experiments are broad-band with a spectral response approximately matching the skin erythema *C.I.E.* action spectrum [Diffey, 1984]. They provide the erythemal *DR* between 200 and 400 nm with a typical sampling time ranging from some seconds to some minutes. The waveband is selected by means of the detector and of coloured glass filters. A phosphor filter converts incoming *UVB* radiation to green light, which is then measured by a solid state photodetector. These instruments are equipped with an internal temperature control system for the phosphor and the optics, which heats at +45°C (when the ambient temperature ranges between –40°C and +40°C). Broad-band radiometers should be regularly calibrated with reference to a near spectroradiometer (such as Brewer and Bentham instruments). The estimated uncertainty of well maintained spectroradiometers is within 5%, while broad-band radiometers'accuracy is about 10%.
The Solar Radiometry Observatory, "Sapienza" Università di Roma (41.9°N, 12.5°E, 70 m a.s.l.) is one of the stations regularly measuring *UV* irradiance in Italy by a Brewer spectrophotometer and a YES UVB-1 broad-band radiometer operational since 1992 and since 2000, respectively. Both instruments are calibrated on a regular basis and their uncertainty ranges from 5 to 10%.

4.2 Polysulphone dosimeters

Polysulphone dosimetry is the most widely used methodology for assessing *PD* [Davis et al., 1976; Parisi et al., 1997, Siani et al., 2008a]. Polysulphone (*PS*) is a polymer that, when exposed to *UVR*, undergoes a complex photodegradation with increased fragility. The polysulphone monomer is shown in Figure 3.

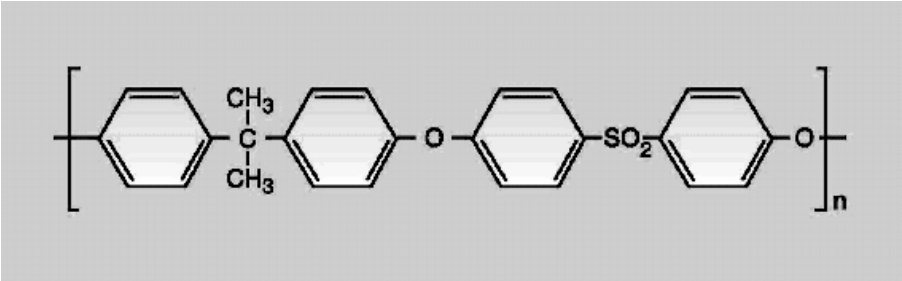

Figure 3: The polysulphone monomer [Davis et al, 1976]

The C-O and C-S bonds are cleaved by *UV* photon action. The C-S bond is more sensitive resulting in its rupture with no inverse reaction. Such degradation generates a variation of *PS* absorbance which can be measured to provide a measurement of the absorbed *UV* dose.
The *PS* film is mounted in a cardboard or photographic holder to form a badge (Figure 4) that is secured to the body site using a pin, Velcro or tape. A first study to measure personal *UV* exposure in adolescents' using *PS* was carried out in 1988 [Lew and Rosenthal, 1988]. Afterwards *PS* badges were used to study personal occupational *UV* exposure [Kimlin et al., 1998; Thieden et al., 2005; Antoine et al., 2007], exposure during other activities [Diffey et al., 1996; Parisi et al., 2000], anatomical differences in *UV* exposure and the influence of Sun protection on *UV* exposure [Kimlin

et al., 2006] and to compare *UV* exposure in different outdoor environments [Boldemann et al, 2004].

Figure 4: A polysulphone dosimeter on the left side, a broad band radiometer on the right side (Solar Radiometry Observatory, "Sapienza" Università di Roma)

PS dosimeters offer several advantages in measuring actual *UV* exposure: they have a response spectrum similar to the erythemal action spectrum; they are temperature independent; the changes in absorbance are related to *UV* dose received and hence they provide a measure of the dose received by the surface to which the dosimeter is attached; they can be miniaturized and attached to a variety of surfaces and anatomic sites; they are waterproof. In addition they are a cheap means for quantifying personal erythemal *UV* doses on many individuals. Their main limitations are: they do not permit to assess dose rates; their sensitivity extends up to wavelengths of 330 nm; the calibration pattern is dependent on film thickness; pre- and post-exposure absorbance measurements may require a labour intensive task; they do not take into account any *UVA*-*UVB* combined effect; they show a slight dark reaction; they must be kept intact, unwrinkled and clean. *PS* dosimetry does not allow to record individual personal dose rates differently from photo-electronic captors.
The use of *PS* dosimetry requires to determine accurately calibration curves under the same atmospheric conditions of exposure of population groups [Casale et al., 2006], due to the discrepancy between *PS* and erythema *C.I.E.* spectra (Figure 5).

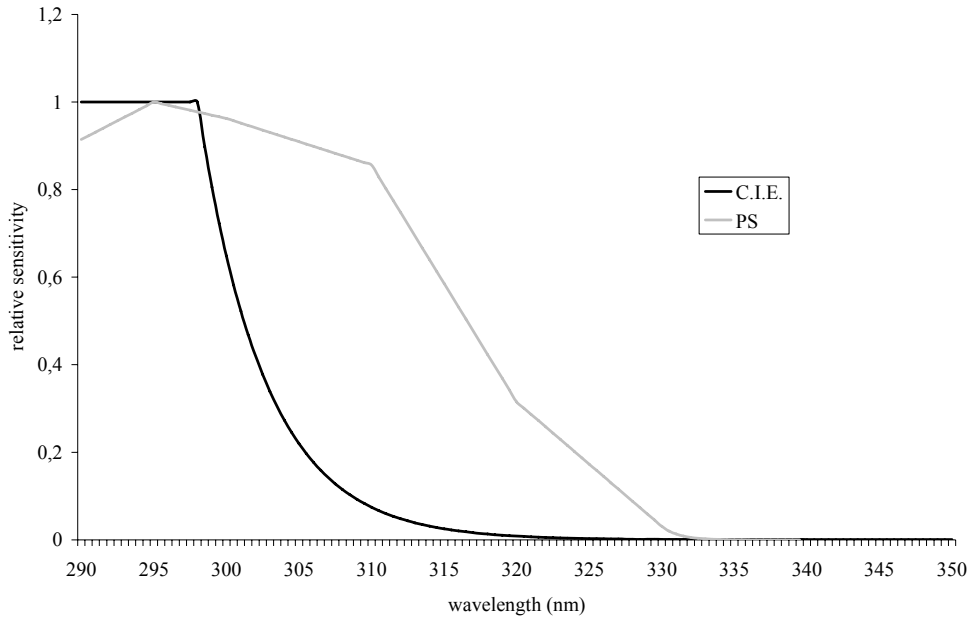

Figure 5: Polysulphone and erythema C.I.E. spectra comparison

Calibration curves are obtained by measuring *AD* and the corresponding change in *PS* film absorbance (ΔA at 330 nm), prior and post exposure [Diffey, 1989]. Typical absorbance of unexposed *PS* films with a thickness of 40 μm at 330 nm ranges from 0.1 to 0.2 (depending on the batch) while under prolonged exposures the film reaches saturation at values of ΔA greater than about 0.4 [Diffey, 1989]. Diffey showed that the best data fit is given by the following equation:

$$AD = c(\Delta A + \Delta A^2 + 9 \cdot \Delta A^3) \qquad [5]$$

4.3 Colorimeter

Several studies have showed that both reflectance spectrophotometers and tri-stimulus colorimeters are very useful in the quantitative evaluation of *UV*-induced erythema and pigmentation, the severity of diseases and the efficacy of treatment modalities [Park et al., 2002]. Before colorimetric measurements, information on skin colour variation between different body sites to account for variation in skin thickness, blood supply, ambient meteorological conditions (temperature and humidity) and the type of activity is needed [Alaluf et al., 2002]. Instruments should also be placed on identical sites before and after exposure to *UVR.* Freckles and moles must be identified to prevent them from obscuring readings. Visual inspection by a dermatologist to identify erythema and any other skin reactions can validate colorimeter data. The measuring head is gently compressed against the selected body site, a xenon lamp fires, causing a flash, and optical fibres lead the reflected light plus emitted light to silicon photocells for analysis of primary stimulus values for red, green and blue light. Although colorimeters are portable, simple and quick for quantifying erythema with reasonable accuracy, the error in the measurement may result if measures are taken with an incorrect pressure.

The Minolta Spectrophotometer CM26000d (Minolta, Osaka, Japan) was used in our study. It is based on the physical measurement of reflected light, through an integrating sphere, at specific wavelengths (400–700 nm at 10 nm steps), corresponding to the spectrum of visible light. With this instrument it is possible to obtain skin colorimetric values [Park et al, 2002] in the *(L*, a*, b*)* system as defined by the Commission Internationale de l'Eclairage [C.I.E., 1986].

The in-field measurements of skin colour were taken on a non-exposed site (constitutive pigmentation) and on an exposed site and the changes between the two sites, before and after exposure, were used as biological indicators.

4.4 Radiometric thermometer

A PT-3LF portable non-contact thermometer (Optex, Japan) was used to measure skin temperature before and after exposure, following the same procedure of colorimetric measurements. The instrument (planned mainly for applications in electric wiring, motors and machines, freezers and refrigerators) resulted in being quick (response after 1.5 s), safe and reliable (repeatability ±1°C of reading value) also for its new use on human body. With a field of view of 30/1000 mm, it uses a sighting method based on a coaxial laser marker. Optics are made of a silicon lens and its sensing element by a thermopile working in the range 8-14 μm. Its accuracy is ±1% of reading value. Two values of the emissivity ratio ε, 0.95 (dark bodies) and 0.70 (bright bodies), can be chosen.

4.5 Free radicals D-Roms test

The determination of *FR* plasma levels and the effect of antioxidant therapy on these levels was a difficult task. A portable, free radicals determination system called D-Roms test (by Diacron, Grosseto, Italy) was recently developed [Cesarone et al., 1999].
The D-Roms test provides a simple, inexpensive and practical method to identify subjects with a high level of oxidative stress and to demonstrate the effect of any treatment or additive stress.
In the sunbathers field campaign, some volunteers accepted a blood test for the measure of free radicals in the plasma the day before and after their exposure

4.6 Questionnaire

The participants in the sunbathers and the skiers field campaign were asked to complete a questionnaire about the outdoor activity and time spent indoor. They were also asked about their use of sunscreen and protection tools at the beginning and at the end of the exposure.

5. METHODOLOGY

5.1 Subjects selection

Two studies were performed involving volunteering sunbathers and skiers. The rationale for selecting the two targeted populations from which volunteers were sought for assessment of *UVR* exposure follows:

The sunbathers (*SB*) study was designed to investigate whether systematic differences in short-term solar exposure exist between healthy subjects (suntanned and non suntanned individuals) and subjects affected by abnormally high sensitivity to solar exposure (photodermatoses). The field campaign took place on 27th May 2005 on the beach of Fregene (Lat. 41.8°N, Long. 12.2°E, 0 m a.s.l.), a popular sea-side location in central Italy, about 30 km west of Rome.

The Skiers (*SK)* study aimed at the quantification of personal *UV* exposure of ski instructors and skiers who presumably receive highest personal doses. Two field campaigns, in spring (from March 30 to April 4 2006), and in winter (from January 29 to January 30 2007) were carried out at La Thuile-Les Suches ski field (45.7°N, 6.6°E, 2100 m a.s.l.), a mountainous area in Valle d'Aosta region (Italy)

5.2 Volunteers selection

Participation for both field experiments was on a voluntary basis and the study was conducted according to the principles of the Declaration of Helsinki (2000).
In the case of *SB*, 37 volunteers were recruited by means of an advertisement at the Physics Department-"Sapienza" Università di Roma and at the Photo-therapy Laboratory of the IFO S.Gallicano Hospital of Rome. Three groups were selected: subjects already suntanned; subjects with no previous exposure before the field experiments (i.e. non suntanned); subjects with an abnormally high sensitivity to their first *UV* exposure.
In the *SK* , 31 skiers were recruited among the staff of the ARPA Valle d'Aosta (Aosta Valley Regional Environmental Protection Agency) using an advertisement at the ARPA headquarter at Saint-Christophe (Aosta); 31 instructors were recruited voluntarily at La Thuile ski school.

5.3 PS dosimeters calibration

The calibration curve is obtained exposing to solar *UVR* a series of dosimeters on a horizontal plane close to a calibrated broad-band radiometer in order to cover the entire range of *SZA* which can be viewed from the dosimeter worn by volunteers. The calibration curve (ambient dose vs absorbance difference at 330 nm) is best fitted by a cubic polynomial function as expressed by equation (5). Since the *c* coefficient depends on total ozone *O3, SZA* [Casale et al., 2006] and altitude [Siani et al, 2008a], the calibration curve should be determined under the same atmospheric conditions of exposure of population groups. Ambient doses during the SB field campaign were measured using the calibrated YES UVB-1 broad-band radiometer belonging to the Solar Radiometry Observatory "Sapienza" Università di Roma.

The *SB* calibration curve was characterized by a *c* value of (0.63±0.01) kJm^{-2} [Siani et al, 2008b]. In the case of the *SK* field campaigns, ambient doses were measured using a calibrated broad-band UV-S-AE-T radiometer (Kipp&Zonen, The Netherlands), installed on the roof of the building of Espace S. Bernardo cable car directly on the ski-field at La Thuile-Les Suches. The *UV* radiometer belongs to ARPA and its calibration is performed by Calibration Measurement Softwaresolutions (CMS) in Austria every year. A *c* value of (1.69±0.02) kJm^{-2} and (1.28±0.02) kJm^{-2} at La Thuile-Les Suches (2100 m asl), were found in spring and in winter campaigns respectively. The uncertainty associated with *PD* determined by the calibration curves was estimated to be 10% [Diffey, 1989].

5.4 Study protocol

At first, the volunteers gathered on the study location (beach or ski-field) and were asked to follow their usual habits. During the study period they completed a short questionnaire about their posture during the exposure and time spent indoor. They were equipped with a *PS* dosimeter which was secured to the chest using a pin (women) or a tape (men), in the case of *SB,* and on the forehead, for *SK*. In addition, measurements of *L*a*b** colorimetric parameters were taken before and after the exposure in both field campaigns. Skin temperature (T_s) measures were carried out in the *SB* study only. The volunteers were monitored during their exposure by the researchers of "Sapienza" Università di Roma and, in the case of *SB*, by the dermatologist. Furthermore, 16 *SB* volunteers accepted blood test for the measure of *FR* in the plasma the day before and two days after their exposure.

5.5 Statistical analysis

Data were analysed using the Statistical Package for Social Sciences (*SPSS*) software version 14.0. Comparisons of *ER* values, *L*a*b**, were performed using the Wilcoxon Signed Rank test (*WSR)* non-parametric test in alternative to the repeated measures t-test to explore differences within groups [Cohen, 1988]. The Friedman test was used as a non-parametric alternative two-way

repeated measures analysis of variance by ranks to detect differences in *ER* across multiple time slots (repeated measures) jointly to the *WSR* to test for the specific differences between each time slot [Cohen, 1988]. Statistical significance was set at $p \leq 0.05$ (two-tailed). Spearman correlations to compare *ER* with colorimetric readings as well as with *FR* and *Ts* data (*SB* study only) were also used.

6. RESULTS

6.1 Exposure Ratio

In the *SB* study, the maximum exposure time was 134 min centred around local noon. The mean *UV* index was 7.0 (the corresponding climatological value is 6.63 ±0.12 at Rome). The median value of *ER* is 19.8% (min: 9.0%, max: 33.6%) for suntanned individuals; for non suntanned individuals the median is 16.8% (min: 13.3%, max: 41.7%) and for photosensitive individuals is 19.0% (min: 13.8%, max: 33.9%). Such median values have not significant statistical differences among themselves and the average *ER* for the three groups (18.5%) can be considered representative of the targeted population.

In SK study the exposure time interval was approximately from 10:00 to 16:00 LT. Spring campaign was characterized by the maximum *UV* index of 7.5 with a mean value of 7.0 in a time interval of two hours around 12:00 LT, while in winter *UV* index peak was about 2.
The statistical analysis showed that there were no significant differences across the groups of skiers and instructors in their median values in spring: the ER median was 102.0% (min: 46.0%, max: 172.0%). The highest maximum spring value of 172.0% was due to significant diffuse and reflected components experienced by volunteers when skiing in a downhill direction mainly facing towards the sun. In winter there was a significant difference between the two groups: 96.0% (min: 29.0% max: 146.0%) for instructors; 54.0% (min: 42.0% max: 70.0%) for skiers. This can be attributed to the fact that in winter most of ski slopes were in the shade (as derived from self-reported questionnaire) and instructors spent most time standing during lessons. An yearly average value of 96.0% can be determined taking into account the spring values and only winter instructors data. Table 2 shows a summary of the results for the two studies

Table 2: Summary of results for the two studies . The percentage Average ER is reported together with the absolute minimum and maximum values in brackets. In the other columns, L*a*b* values before ($_b$) and after ($_a$) exposure for the exposed site are showed, with the last column reporting the corresponding change (Δ).

		Exposed body site								
study	**Average ER (%)**	**L^*_b**	**a^*_b**	**b^*_b**	**L^*_a**	**a^*_a**	**b^*_a**	**ΔL***	**Δa***	**Δb***
SB	18.5 (9.0-41.7)	60.8	9.7	16.1	57.4	10.1	9.6	-3.4	+0.4	-6.5
SK	96.0 (29.0-172.0)	52.3	13.8	16.3	51.7	13.3	14.8	-0.6	-0.5	-1.5

6.2 Ancillary parameters

Colorimetric values of *L**, *a** and *b** of the non exposed site before exposure showed no significant differences in the median scores across the groups of the *SB* study. Moreover, *L**, *a** and *b** values of the non exposed site did not differ before and after exposure. The same result was found for the *SK* study. This means that the constitutive pigmentation of volunteers is not altered in the photoprotected body sites. Before exposure, in the *SB* the *L** median value was consistently higher compared to *L** taken after exposure among the three groups, with an average difference of -3.4 (not statistically significant). An average difference after-before of +0.4 (not statistically

significant) and -6.5 (statistically significant) was indeed found for the a^* and b^* parameter, respectively.

In the *SK* study both skiers and instructors had on average significantly lower median L^* and b^* after exposure in both seasons (average values of change -0.6 and -1.5, respectively, with $p<0.001$). This means that all subjects changed their skin pigmentation becoming darker after exposure. The difference of a^* (-0.5) between post-exposure and pre exposure was, on the other side, not significant. Regarding the results on *Ts* analysis of the *SB* study, although all participant groups had the same median skin temperature of 37°C before exposure, there were statistically significantly lower temperatures (35°C) after sun exposure compared to those before exposure in all participants, taking into account the uncertainty of measure $\Delta T_s=\pm 1$°C. The analysis on free radicals amounts showed that the values were not significantly different across the sunbather groups, except for the non suntanned group. In this case a significantly larger number of *FR* after sun exposure compared to before exposure ($p=0.028$) was found.

6.3 Correlation between Exposure Ratio and ancillary parameters

A moderate inverse correlation ($r=-0.426$) was found between *ER* and the change in b^* (at significance level $p<0.001$ in the *SB* study. L^* and b^* after exposure were both weakly negatively correlated with *ER* ($r=-0.373$ and $r=-0.388$ respectively, at $p<0.05$), while b^* before exposure was the only variable showing a positive small correlation ($r=0.369$, $p<0.05$) with *ER*. There was no correlation with changes in skin temperature and in *FR* amounts. Finally, there was no statistically significant association between *ER* and ancillary parameters in the SK study.

CONCLUSIONS

The investigation on sunbathers (SB) and skiers (SK), the first one of this type in Italy, provided new data in terms of Exposure Ratio. The *SB* study indicated that the exposed site (chest) received a personal dose ranging from the minimum of 9% of ambient dose to a maximum of 41.7%. The correlation values showed that photodermatoses are not related to *ER* and to changes in colorimetric parameters, skin temperature or free radicals amount, probably due to the short duration of *UV* exposure.In the *SK* study the personal dose ranged from 29.0% to 172.0% of the ambient dose. Although a direct comparison with the *SB* study is not possible (mainly due to the different position of the *PS* badge), the findings provided evidence that exposure on ski-field resulted consistently higher than the *SB* study even when the ambient *UV* levels were characterized by high comparable *UV* index values (see *UV* index values in spring and sunbather campaigns). This is due to the fact that *ER* parameter is less dependent on the environmental exposure conditions than the personal dose and it can be considered an appropriate parameter to characterize exposure of different behavioural postures related to the outdoor activity.

No correlation was found between *ER* and colorimetric parameters. Possible visible changes in skin colour can be observed after longer time intervals after exposure.

A careful investigation of long term endogenous effects will be carried out in further in-field campaigns aiming at this specific goal.

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