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Extreme UV index and solar exposures at Plateau Rosà (3500 m a.s.l.) in Valle d'Aosta Region, Italy

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HIGHLIGHTS

- PS and PPO dosimeters measure UV exposures over short/prolonged periods, respectively.
- Large UV exposures of skiers were found.
- The facial exposure is always higher than the threshold exposure limit.

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ABSTRACT

The purpose of this study is to assess personal exposures of skiers at the Alpine site of Plateau Rosà (45.9°N, 7.7°E, 3500 m a.s.l.), in the Valle d'Aosta region, Italy. The campaign was carried out on July 12th, 2011 during the summer ski season. A peak UVI value of 12.3, among the highest in Europe, was recorded on that day. Personal exposures (PE) were quantified using both polysulphone (PS) and poly-dimethyl phenylene oxide (PPO) dosimeters attached vertically to the cap because it is representative of the vertically oriented face of skiers. Exposure ratio (ER) defined as the ratio between PE and the corresponding ambient dose (i.e. erythemally weighted dose received by a horizontal surface) measured by a broad-band radiometer during the same exposure time of the subjects, was used to compare the results with previous studies. Skin color was also measured on the inner upper arm and on the cheek and differences in ITA (Individual Typology Angle) and a^* (redness) values before and after exposure, were statistically analyzed.
During the exposure period, the median PE (with PS) was 1.47 kJ m^{-2} and that obtained by PPO was 1.15 kJ m^{-2}. The median of the ERs was 0.65 (min: 0.50, max: 0.83) considering the cumulative PS exposure and 0.46 (min: 0.29, max: 0.95) for PPO. An increase in ITAs on the exposed site (i.e. the skin became lighter) was observed after exposure. These results indicate that: a) for some skiers, the exposures were similar to those received on the horizontal plane; and b) the targeted population showed exposures above the occupational threshold limit value (TLV) defined by ICNIRP; c) the use of physical sunscreens which tend to leave a white cast, might have reduced skin color change. Nevertheless possible visible sun-induced skin-color changes could be observed after longer time intervals after exposure.

1. Introduction

Experimental and epidemiological evidence has shown that high solar UV exposure is an environmental risk factor for some types of skin and a reason of eye disorders (e.g. Juzeniene et al., 2011). The received solar UV dose, however cannot be easily assessed, since it depends on atmospheric and environmental factors and sun exposure behavior, i.e. on posture, duration in the sun, clothing and sun-protective devices (e.g. Petersen et al., 2013).

There is large seasonal and geographical variability in surface UV levels which is mainly controlled by variations in atmospheric transmission (primarily due to ozone absorption in the upper atmosphere, aerosols and clouds), by astronomical factors and surface reflections. For instance the combined effects of shorter radiation path-length and low aerosol load in high elevation regions can contribute to peak levels of UV radiation (Dahlback et al., 2007; Cordero et al., 2014; Zaratti et al.,

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2014). Furthermore, environments characterized by high albedo (defined as the percentage of the irradiance reflected by a horizontal surface with reference to the incoming surface (e.g. Simic et al., 2011) and the reflectivity of tilted surrounding surfaces), can lead to much greater exposure of vertical human body sites (eyes and face) to UV radiation due to multiple reflections from the surfaces (e.g. Grifoni et al., 2006). Therefore, Alpine environments experience higher UV radiation levels than sea level (Meloni et al., 2000; Schmucki and Philipona, 2002; Seckmeyer et al., 2008; Simic, et al., 2008; Rieder et al., 2010). In the above-mentioned studies, however, surface ultraviolet radiation was measured on a horizontal surface which provides only partial information of individual exposure since differently oriented body surfaces receive different levels of radiation.

In summer, mountainous sites, with the concurrent effect of high reflectivity of snow, represent an ideal environment laboratory to study the impact of elevated UV levels on humans. The face is particularly subject to solar injury because of its significantly greater exposure with respect to other anatomical sites (=ICNIRP, 2007) in the case of snow-covered surfaces and the risk of developing squamous cell carcinoma increases (Rosso et al., 1999).

For this reason we conducted a field campaign in the period close to the UV summer peak (due to the concurrent effects of low solar zenith angle and total ozone amounts) at one of the highest Alpine measurement sites in Italy: Plateau Rosà (45.9°N, 7.7°E, 3500 m a.s.l.), in Valle d'Aosta region. Although skiing is in general considered a winter sport, summer skiing is also practiced by both athletes and amateurs.

This work is a follow-up of previous research with skiers (Siani et al., 2008) carried out at La Thuile-Les Suches ski field (45.7°N, 6.6°E, 2100 m a.s.l.), another Alpine site in the same region, during spring 2006 and winter 2007 using polysulphone dosimetry.

The aim of the present study is summarized as follows:

1) to analyze the calibration curves of two chemical dosimetric techniques: polysulphone (PS) and poly-dimethyl phenylene oxide (PPO) obtained during field campaigns carried out under extreme UV conditions and at two different radiative environments (an urban site and a mountain site with snow-free surroundings);
2) to compare the long term personal UV exposures measured simultaneously by PS and PPO dosimeters;
3) to quantify the UV exposures of summer skiers in terms of exposure ratio (i.e. the ratio between the dose received by skiers and the ambient dose measured on a horizontal plane) and to evaluate whether the exposure of the targeted population is within the threshold limits recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP);
4) to evaluate pigmentation changes (if any) induced by UV exposures.

2. Materials and methods

2.1. Study locations

Three sites were considered in this study: Plateau Rosà (45.9°N, 7.7°E, 3500 m above sea level, a.s.l.), Saint-Christophe, Aosta (45.8°N, 7.4°E, 569 m a.s.l.) and Rome (41.9°N, 12.5°E, 70 m a.s.l.).

Plateau Rosà is an alpine ski resort at the foot of the Cervino-Matterhorn mountain, located on the border between Switzerland and Italy, where summer skiing is practiced. A field campaign involving a sample of skiers took place at this site on July 12th, 2011. The calibration of PS and PPO dosimeters was carried out on the same day and at the same site.

Saint-Christophe, Aosta (hereafter called Aosta) was also selected for the dosimetric calibrations since it is located at lower altitude but geographically close to Plateau Rosà and with snow-free surroundings during summer (e.g. Diémoz et al., 2013). At this site, the calibrations were not performed on the same day of the campaign as the research team was involved at Plateau Rosà. The dosimetric calibrations were carried out on August 9th characterized by similar total ozone amounts compared to July 12th. This parameter together with the solar zenith angle is the main factor affecting the variability of the calibration curves (Casale et al., 2006). Rome was also included in the dosimetric calibration campaign as an additional geographical location because of its peculiar environmental features as an urban site at lower latitude.

2.2. Instrumentation

The ambient dose (or ambient exposure) is defined as the integrated erythemally-weighted irradiance over a specified period of time (C.I.E., 2014). The erythemally-weighted UV irradiance is calculated by convolving the spectral irradiances with the spectral weighting function for erythema (ISO/C.I.E., 1998). The adimensional parameter called UV index (UVI) (Cost-713, 2000) is obtained by scaling the erythemally-weighted UV irradiance by 25 mW m^{-2}. The UVI values can range between 0 (during the night) and more than 10 "extreme values" (Zaratti et al., 2014).

Measurements of ambient doses for the calibration curve were carried out using a calibrated UV-S-AE-T (Kipp&Zonen) broad band radiometer at Plateau Rosà in operation since 2006. In addition, UV doses were also recorded by a broad-band radiometer (same model as in Plateau Rosà) operational since 2004 at the headquarter of ARPA Valle d'Aosta (Aosta Valley Regional Environmental Protection Agency) at Saint Christophe, Aosta. Both radiometers belong to ARPA Valle d'Aosta and provide the erythemal dose rate between 280 and 400 nm with a sampling time of 10 s. The instruments are characterize every year at the PMOD/WRC (Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, see http://www.pmodwrc.ch/euvc/euvc.html), and absolutely calibrated at Aosta with reference to a double monochromator spectroradiometer traceable to the QASUME World standard (Gröbner et al., 2005; Diémoz et al., 2011).

Spectral UV irradiances measured by the Brewer MKIV spectrophotometer (n.67) were used to retrieve the erythemally-weighted UV irradiances, the UVI values and the exposures for the calibration curve at Rome. The UV spectra were preliminarily corrected for straylight, temperature and angular response. The SHICrivm code (version 3_075) was applied to the UV spectra to check any spectral wavelength shift and spectral anomalies (Slaper et al., 1995). The same software was used to retrieve the erythemally-weighted UV irradiances up to 400 nm, since the Brewer scan is carried out till 325 nm. The overall performance of the Brewer instruments is checked about every two years by intercomparison with the traveling Brewer n.17 operated by the International Ozone Service. The last comparison with the UV reference spectroradiometer, carried out in 2012 at Arosa (Switzerland) showed that the mean ratio of Brewer global solar UV irradiances to the QASUME spectroradiometer was +3%.

Ozone values were measured by the Brewer spectrophotometer at Rome. OMI (Ozone Monitoring Instrument) gridded total ozone data were used for the Valle d'Aosta region. Total ozone amounts based on TOMS algorithm (version 3 daily level 3 global 0.25° gridded data) were downloaded from the Giovanni online data system, and developed and maintained by the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC).

2.3. Polysulphone and poly-dimethyl phenylene oxide dosimetry

Chemical UV dosimeters are based on the use of polymers which undergo photo-degradation when exposed to UV radiation and increase monotonically the optical absorbance.

Polysulphone dosimeters have been successfully employed in several personal exposure studies in both outdoor working and recreational activities (Casale et al., 2011). The C.I.E. PS spectral response (C.I.E., 1992) resembles the erythemal action spectrum (Diffey, 1984). Polysulphone is thermally stable (Diffey and Davis, 1978), the dark reaction is known and the dosimeters exhibit a good angular response for incident angles up to 70° (Casale et al., 2012). PS dosimeters are light and cheap; these properties enable PS dosimeters to be used in field campaigns with a statistically significant number of volunteers (Siani