Analysis of the diurnal distribution of Ultraviolet exposure on upper body anatomical sites for outdoor workers

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Abstract: - Many workers perform their daily activities outdoors and many anatomical body sites are exposed to UV radiation. The effects of solar radiation on human health depend on the amount and type of radiation impinging on the body. This paper aims to investigate and analyse the diurnal UV radiation exposure at typical anatomical site for farm workers. The diurnal distribution in solar UV exposure at the nape of the neck, forearm, forehead and cheek of farm workers was measured at 15 min intervals for consecutive working days from January to July 2012. The anatomical site most exposed was the nape of the neck. The UV exposure at the nape of the neck indicates that when SEA is about 54°, it may receive maximal exposures depending also on the particular anatomical site orientation and body movements. To better understand the diurnal distribution and variation of UV exposure, a correlation between solar elevation angle and UV exposure was investigated. The correlations were determined for each anatomical body sites with a R^2 in a range between the 0.87 and 0.99. Real time exposure data suggest that it is useful to remind workers of the UV radiation risks associated with spending increased time in the sun exposure.

Key-Words: - : farm workers, UV radiation, solar elevation angle (SEA), correlation SEA UV exposure

1 Introduction

The diurnal and annual variability of solar UV radiation reaching the ground is governed by astronomical and geographical parameters as well as by the atmospheric conditions. Since human activities affect the atmosphere, such as polluting the air and influencing the ozone layer, they also affect the UV radiation reaching the ground. As a consequence, solar UV radiation is a highly variable environmental parameter that differs widely in time and space.

The adverse effects of sunlight exposure are numerous [1 and 2]. The effect of solar radiation on human health depends on the amount and type of radiation impinging on the body. This in turn depends on, firstly, the concentration of atmospheric ozone that is available to absorb ultraviolet radiation, particularly UVB. Next, the amount and spectral structure of radiation reaching the body is dependent on the angle at which the sun's rays pass through the atmosphere – at low latitudes (closer to the equator) there is more intense solar UV radiation with a greater proportion of shorter wavelengths, related to the low angle of incidence of the incoming radiation. This strongly influences biological activity. Increasing altitude increases UV radiation intensity by decreasing the air mass through which solar radiation must pass. Similarly, time of day and season as well as presence of clouds, dust, haze and various organic compounds can alter the intensity of incident solar radiation.

The exposure distribution of populations is unclear. While data on ambient UV radiation is available, this does not easily translate to actual population exposure distribution. Measurements of ambient UV radiation give an indication of the "possible" UV radiation exposure of a population.

However, the relationship between an outcome and the risk factor occurs at an individual level. Understanding the population distribution of personal UV radiation exposure under a particular level of ambient UV radiation is not straightforward. In addition to difficulties in ascertaining accurate exposure data, for many diseases there is a long lag period between exposure to the risk factor and development of the disease. For some diseases, such as cutaneous melanoma and basal cell carcinoma of the skin, it is likely that the relationship is not a simple dose-response relationship, but may involve thresholds of UV exposure as well as critical life stages of exposure [3]. The outdoor workers have some exposure to ultraviolet radiation on a daily basis. So many studies have measured the solar UV exposure for five occupations [4], for office workers [5], for building and construction workers [6, 7 and 8], for mountain guides [9], for post mail delivery personnel and physical education teachers [10], for gardeners [11], for professional cyclists [12], for outdoor, indoor and mixed occupations [13], for outdoor workers, home workers, adolescents, indoor workers, school staff and students [14], for farmers [15] and related to age, sex and occupation [16 and 17].

To quantify the effects of solar UV radiation on the human body, researchers have also studied the UV radiation received on inclined planes (especially the sun-normal and vertical planes) to simulate body posture [18, 19, 20 and 21] as well as stationary or rotating manikins [22, 23 and 24]. However there seem to be a limited number of studies concerning agricultural workers; the exposure of these workers to high levels of UV radiation should be explored for health risks. In 2011, one third of the world's workers were employed in agriculture and agriculture is one of the three most dangerous sectors in terms of work-related fatalities, non-fatal accidents and occupational diseases for child labor. About 59 percent (or 70 millions) of all children in hazardous work aged 5–17 are in agriculture [25].

In this research the realistic measurements at typical anatomical sites were carried out for farm workers in a research farm of Central Italy. Some dosimeters were used to measure the UV exposure for farm workers during the usual working days and during the usual agricultural activities in 2012. As the UV irradiance depends strongly on the solar elevation, on season and day time, the measured data were analysed. The dependence of UV exposure from solar elevation angle (SEA) was investigated. A correlation between solar elevation angle and UV exposure was carried out to better understand the diurnal distribution and variation of UV exposure.

2 Materials and Method

2.1 Equipment and specific anatomic sites

The incident irradiance on a horizontal surface (Wm^{-2}) over a specific period of time was measured using a spectrometer (model CAS120, Instrument Systems). The spectrometer was placed on the ground in an exposed, unobstructed area near the farm workers.

The incident erythemally weighted irradiance over a specific period of time (Jm^{-2}), called UV exposure, was measured on some specific anatomic sites (forearm, cheek, nape of the neck and forehead) using personal dosimeters (model X-2000-10, Gigahertz-Optik).

2.1.1 Geographic and meteorological conditions

The investigation of UV exposure was carried out in the Azienda Agraria Didattico-Sperimentale of the Università Politecnica delle Marche in 2012. The Azienda Agraria is located in Agugliano (Latitude 43°32'40''N, Longitude 13°23'25''E) at a mean altitude of 195 m above sea level.

All of the measurements were acquired on sunny days with clear skies or minimal cloud cover. Whether to collect a measurement depended upon the local weather forecast. The measurements were conducted when the mornings were sunny, but the measurement plans were aborted in the event of inclement weather during the day.

2.1.2 UV exposure measurements

Seven farm workers of the Azienda Agraria were selected to investigate anatomical distribution of UV radiation during the usual agricultural activities. The mean age of workers was 37; four were female and three were male. Personal UV radiation exposure was measured during the farm workers' usual working days. The farm workers were asked to follow their usual working habits. The farm workers completed a questionnaire during the exposure about the description of the activity within the measurement time period, the body posture, time intervals and general questions on the basis of the observation of hair and eye colours and skin pigmentation and their capacity to sunburn. In addition they were asked if they used sunscreen protection and other sun protections (glasses, long sleeves, ect.). Each farm workers was equipped with personal dosimeters that were secured to forearm and forehead using an adhesive and to the cheek and nape of the neck using tape. The UV exposure values were measured at 15 min intervals from 10:00 a.m. to 12:00 p.m. (lunch time from 12:00 p.m. to 2:00 p.m.) and from 2:00 to 4:00 p.m. local time for a maximum time interval of 4 hours characterized by higher UV levels during the year 2012. The farm workers sought shade on their lunch break. The upper body was exposed to a UV radiation regimen that often changed on second-to-second time-scale.

3 Results and Discussion

The UV radiation distribution at anatomical sites varies with the solar elevation angle, atmospheric composition and ground albedo. The UV exposure from 10:00 a.m. to 4:00 p.m. in winter, spring and some summer months in clear sky conditions are analysed, taking into account solar elevations angles (SEA) between 18° and 69°. The arithmetic mean SEA at different time are shown in Table 1.

Table 1. Arithmetic mean solar elevation angle (SEA)

Time	January SEA (°)	February SEA (°)	March SEA (°)
10:00	18.68	24.51	35.40
10:30	21.39	27.56	38.80
11:00	23.51	29.98	41.52
11:30	24.97	31.70	43.42
12:00	25.72	32.65	44.40
2:00	21.50	28.43	38.75
2:30	18.81	25.58	35.35
3:00	15.58	22.17	31.39
3:30	11.90	18.28	26.99
4:00	7.82	13.99	22.26

Time	April SEA (°)	May SEA (°)	June SEA (°)	July SEA (°)
10:00	46.55	54.46	56.89	54.59
10:30	50.32	58.68	61.45	59.10
11:00	53.33	62.14	65.34	62.96
11:30	55.37	64.51	68.17	65.83
12:00	56.25	65.45	69.48	67.31
2:00	48.19	55.27	59.01	58.13
2:30	44.08	50.62	54.20	53.51
3:00	39.50	45.63	49.08	48.51
3:30	34.59	40.41	43.78	43.29
4:00	29.45	35.06	38.39	37.93

The daily UV exposure geometric mean was calculated and analysed for each site of the body under test (nape of the neck, forearm, forehead and cheek). To reduce the influence of the season and weather conditions the percentage ambient UV radiation was calculated as the workers' personal UV for a given time period divided by the concurrent available ambient UV radiation.

The percentage ambient UV radiation exposure is presented in Fig. 1. The nape of the neck exhibited the highest percentage ambient UV radiation (105.93% in April) and the cheek was associated with the lowest (42.37% in June). The percentage ambient UV exposures at the nape of the neck vary in a range between 93% and 106%, while at the cheek it varies between 42% and 48%. The forearm ratios (the ratio between the UV exposure at a particular anatomical site and the horizontal dose) were higher than the forehead ratios in all months with a maximum value of 57.68% in February. All variations in exposure at the nape of the neck, forearm, forehead and cheek sites received more than 42.37% of the mean ambient UV radiation. The calculated percentage ambient UV radiation shows that the upper limit reference interval exceeds 100%, this fact is presumably due to ground reflection, posture and movements.

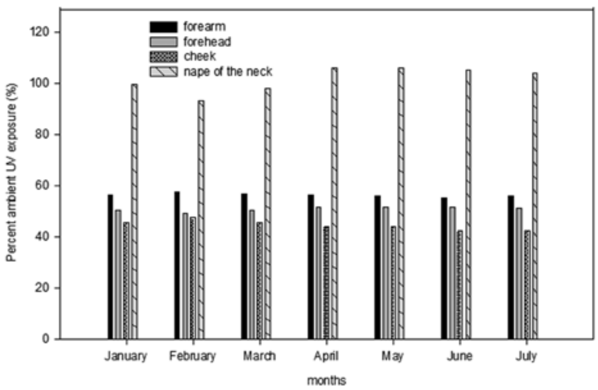

Fig.1. The percentage ambient UV radiation exposure at the four anatomical sites in the months under test

The UV exposures geometric mean by hour on the horizon, at the nape of the neck, forearm, forehead and cheek during the months under test are plotted in Fig. 2, 3a, 3b, 3c and 3d.

The UV exposures can be ordered across season as follows: winter < spring < summer. In each month the diurnal variations in solar UV exposure at each anatomical site shows two peaks, one in the morning at the range about 10:30-11:30 a.m. and the other one in the afternoon at the range about 2:30-3:30 p.m., except at the forearm in which it shows three peaks (one peak around 11:30 a.m. and two peaks around 2:00 p.m and 3:30 p.m.).Farm workers are proibited from working during the central hours of the day bu local regulations.

The UV exposure at the nape of the neck shows a maximum value of 38.02 Wm^{-2} measured at 2:30 p.m. in June, at the forearm it shows a maximum value of 20.05 Wm^{-2} measured at 11:30 a.m. in July, at the forehead the maximum value is 15.79 Wm^{-2} at 2:30 p.m. in June and at cheek it is 12.53 Wm^{-2} at

11:30 a.m. in July. This fact is due to the particular anatomical sites' orientation and body movements.

The pattern at the forearm is relevantly different from the other ones. The anatomical sites can be placed in a descending order of UV exposure as follow: nape of the neck > forearm > forehead > cheek. This fact can be justified by particular anatomical site orientation, body movements and SEA.

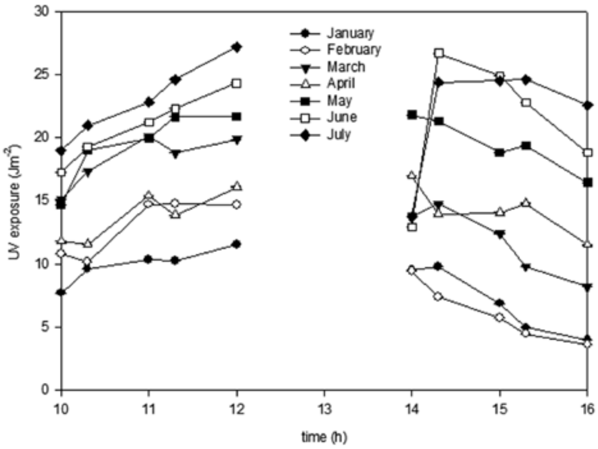

Figure 2. UV exposures geometric mean by hour on the horizon

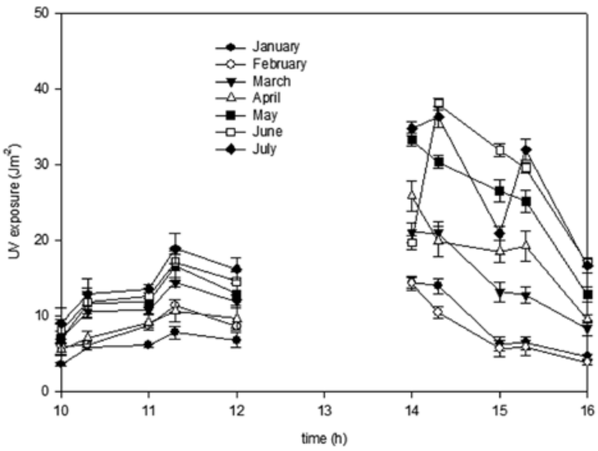

Figure 3a. UV radiation exposures geometric mean by hour at the nape of the neck

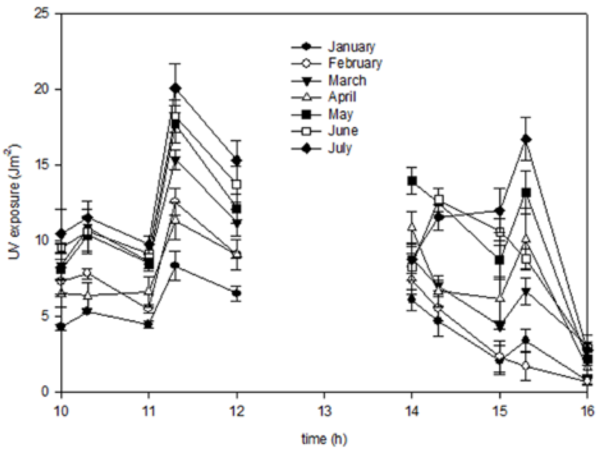

Figure 3b. UV radiation exposures geometric mean by hour at the forearm

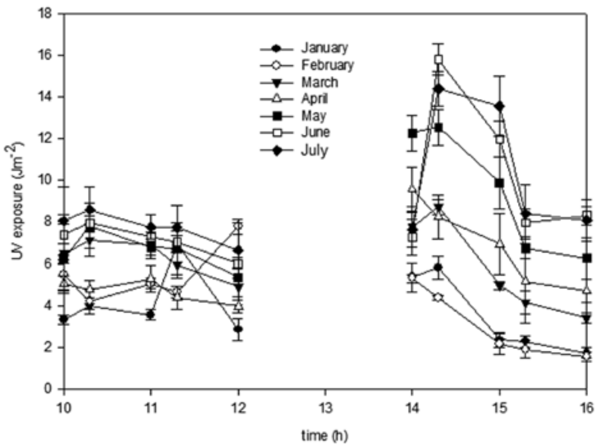

Figure 3c. UV radiation exposures geometric mean by hour at the forehead

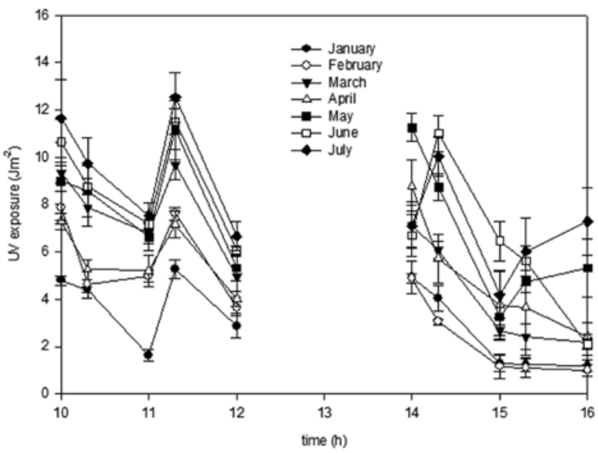

Figure 3d. UV radiation exposures geometric mean by hour at the cheek

The UV exposure at the nape of the neck shows higher values in the afternoon. The forehead exhibited higher values in the afternoon except in January and February. The trend of UV exposure at the forearm and cheek was similar in both the morning and afternoon.

The UV exposure at some anatomical sites varied with anatomical site orientation and solar elevation angle. For high solar elevations the UV radiation was more intense because the rays from the sun have a shorter path through the atmosphere and therefore pass through a smaller amount of absorbers. Fig. 4, 5a, 5b, 5c and 5d show how the distribution of UV exposure on the horizontal plane, at the nape of the neck, forearm, forehead and cheek varied with the SEA. UV exposures increase with greater SEA. The peaks of the UV radiation exposure at nape of the neck and at the forehead were approximately at 54° (SEA) and at about 66° for the forearm and cheek. In winter the highest SEA was about 32° and the UV radiation exposure increased along with the increase of SEA. UV radiation exposure reached a maximum when the SEA was at its highest value in summer.

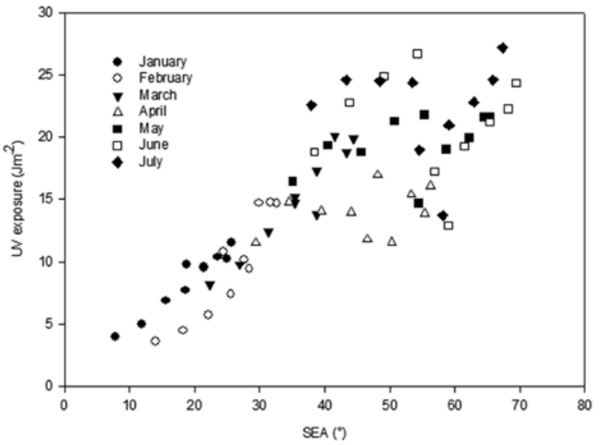

Figure 4. UVR exposure on the horizon versus the SEA

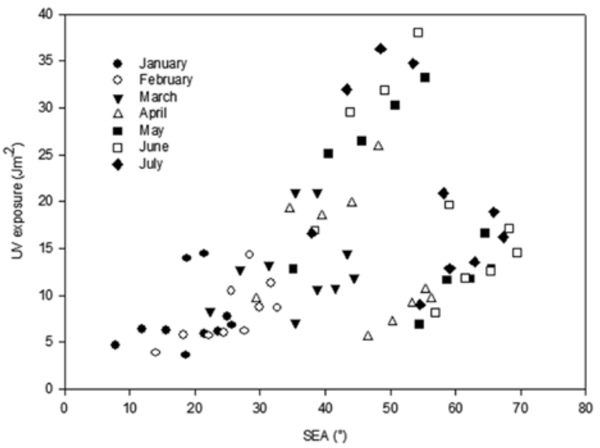

Figure 5a. UVR exposure at the nape of the neck versus the SEA

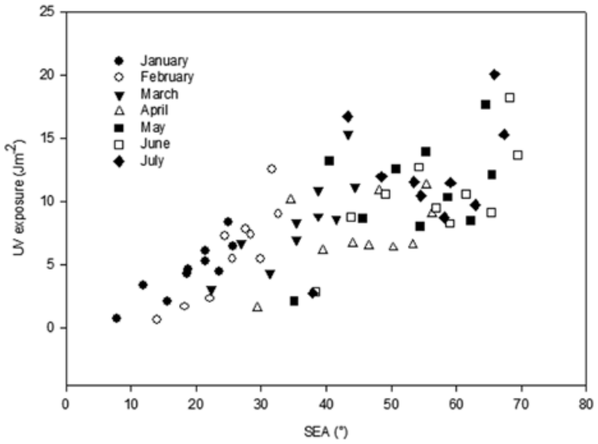

Figure 5b. UVR exposure at the forearm versus the SEA

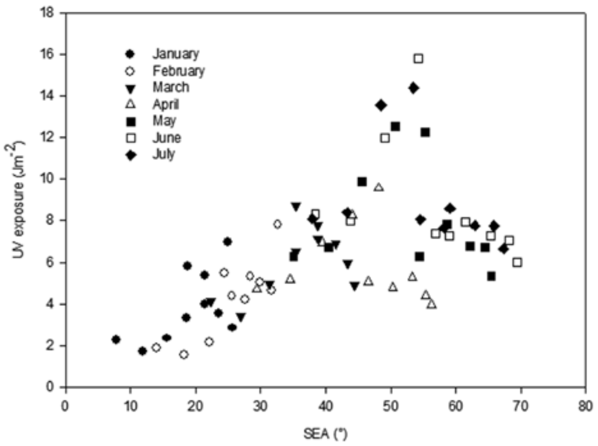

Figure 5c. UVR exposure at the forehead versus the SEA

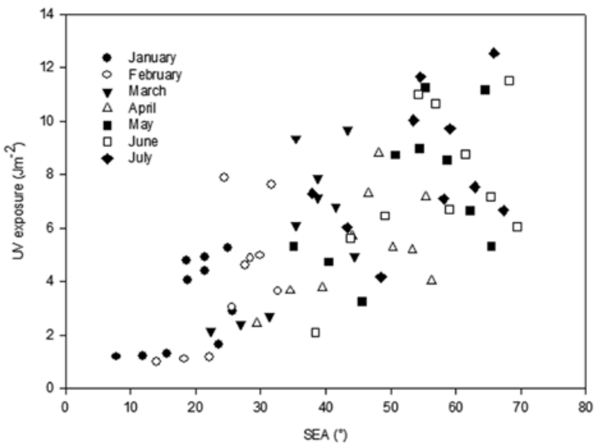

Figure 5d. UVR exposure at the cheek versus the SEA

For the most exposed anatomical site (nape of the neck) a correlation between solar elevation angle and UV exposure was elaborated and analysed in winter (January, February), spring (March, April) and in May, June, July months for the morning and afternoon. This choice was dictated by the fact that workers were not monitored during the lunch break from 12:00 p.m. to 2:00 p.m.. The general correlation is as follows:

$$y=ax^3+bx^2+cx+d \quad (1)$$

where the x-axis is the SEA (°) and the y-axis is the UV exposure (Jm^{-2}).

The values of the parameters of Eq. (1) and the values of R^2 are shown in Table 2 for the morning and in Table 3 for the afternoon. The R^2 is the indicator that describes the fitting of the function to the experimental data. The correlation was determined for the nape of the neck with R^2 in a range between the 0.87 and 0.99. Fig. 6a and 6b show the graphs of the correlation for the nape of the neck in May, June and July.

Table 2. Correlation parameters for the morning

nape of the neck	a	b	c	d	R^2
January - February	-0.04	3.45	-86.03	712.18	0.88
March - April	-0.01	1.72	-76.68	1132.5	0.88
May – June - July	-0.006	1.14	-68.10	1339	0.87

Table 3. Correlation parameters for the afternoon

nape of the neck	a	b	c	d	R^2
January - February	0.001	-0.05	0.65	0.61	0.93
March - April	-0.008	1.01	-38.81	498.30	0.99
May – June - July	-0.010	0.18	1.47	-103.30	0.96

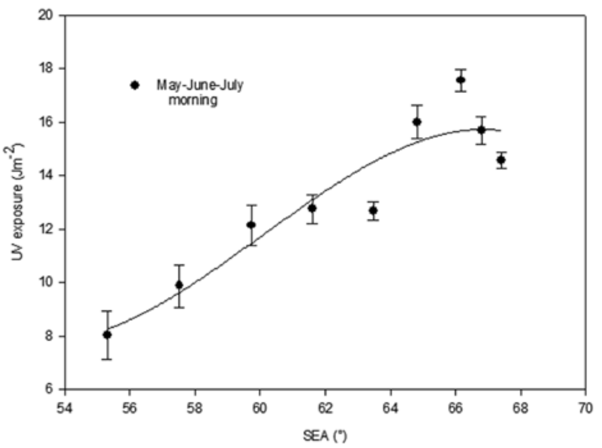

Fig. 6a. UV exposure at the nape of the neck versus the SEA in May-June-July for the morning

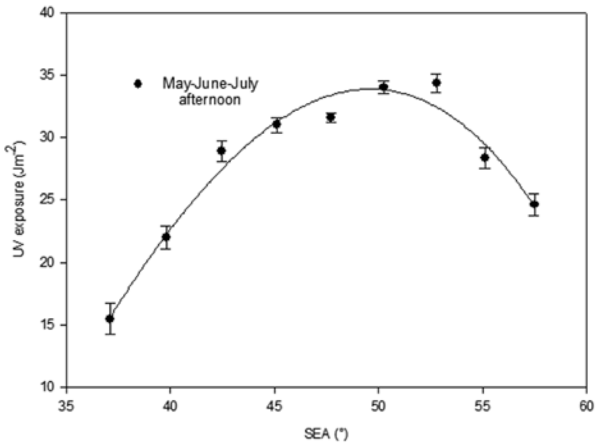

Fig. 6b. UV exposure at the nape of the neck versus the SEA in May-June-July for the afternoon.

4 Conclusion

The UVR exposure at the nape of the neck, forearm, forehead, and cheek was monitored for seven farmers in the Azienda Agraria to investigate and analyse the diurnal variation and distribution of UV radiation exposure. Measurements were carried out during the usual working days and usual agricultural activities for seven months from 10 a.m. to 4 p.m. characterized by highest UV radiation levels. There were no relevant differences in the percentages of ambient exposure and in the UV exposure of the workers. The exposure to each site was dependent on the particular anatomical site orientation. The UV exposure at each anatomical site reaches two peaks, one in the morning and the other one in the afternoon depending on the labor schedule during the day, which has a lunch break from noon to 2:00 pm. The anatomical site most exposed was the nape of the neck, then in descending order the forearm, forehead and cheek. The UV exposure at the nape of the neck indicates that when SEA is about 54°, the nape of the neck may potentially receive maximal exposures depending also on the particular anatomical site orientation and body movements. To better understand the diurnal distribution and variation of UV exposure, a correlation between solar elevation angle and UV exposure was investigated. The correlation was carried out for the nape of the neck and for each average morning and afternoon of each month under test with a minimum R^2 value of 0.87 and a maximum R^2 value of 0.99. The results of this study can be potentially helpful in preventing UV radiation diseases, above all, at the nape of the neck. In fact there are many workers that perform their daily activities outdoors undertaking different postures and many anatomical body sites are UV exposed. Real-time exposure data suggests that it may be useful to remind workers of the risks associated with spending increased time in the sun, not forgetting that almost everyone has some exposure to ultraviolet radiation on a daily basis. It is an exposure that cannot be entirely avoided and, anyway, to strive for zero UV exposure would create the huge burden of skeletal disease from vitamin D deficiency. However, evaluation of the burden of disease created by excess exposure to UV radiation is very important since avoidance of excess exposure is a relatively simple public health message. Nevertheless, further research is required to collect data on the exposure ratios for each month of the year, for different atmospheric conditions and surface albedo and for the different standing postures of outdoor workers.

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