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Might outdoor heat stress be considered a proxy for the unperceivable effect of the ultraviolet-induced risk of erythema in Florence?

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A R T I C L E I N F O

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A B S T R A C T

Erythema is the most familiar short-term symptom of human skin associated with overexposure to unperceivable ultraviolet radiation (UV). However, people are able to perceive the warm infrared component of the solar radiation by means of thermal (dis)comfort. This study investigated the potentiality of perceived outdoor heat stress as a valuable proxy for the unperceivable effect of UV-induced risk of erythema in a Mediterranean city. Meteorological data and UVB (280–320 nm) measurements were obtained for the 2004–2012 period by a weather station located in the municipality of Florence. Continuous measurements of erythemally effective UV (UV_{Ery}) were performed by means of a broadband temperature-corrected radiometer with the spectral response close to the erythemal action spectrum. Hourly UV_{Ery} doses were expressed as Standard Erythemal Doses (SEDs). The newly developed Universal Thermal Climate Index (UTCI), that represents the state-of-the-art of outdoor thermal (dis)comfort evaluation, was also assessed. Descriptive analyses of the hourly distribution per month of the frequencies of days with heat stress and UV_{Ery} exceeding 2.0, 3.0, 4.5 and 6.0 SEDs were carried out based on the general skin-type characteristics.

The association between UV_{Ery} and UTCI was analyzed by a two-way contingency table approach.

The probability of UV_{Ery} exceeding specific SED thresholds when heat stress occurs was often significantly higher than the same probability when no heat stress is perceived. Furthermore, increased magnitudes of the ratios, ranging from the very sensitive to the minimally sensitive skin types, were also found. However, during several months, too many days occur without any signs of heat discomfort, even when people may be exposed to relevant doses of harmful UV_{Ery} for the skin of various phototypes. These findings underlie the need for public health authorities to provide differentiated advice per month in relation to potential UV skin damage in the city of Florence.

1. Introduction

Solar radiation affects human beings in different ways with direct effects occurring when people are exposed outdoors during working or leisure/sport activities. Much attention has been paid to the effects of ultraviolet (UV) radiation (wavelengths between 290 and 400 nm) which only represents less than 9% of the total solar irradiance. Nevertheless, UV radiation is considered to induce the most pronounced beneficial and especially deleterious biological effects on human health. The main well-established beneficial effect of solar UV on the skin is the production of vitamin D required for skeletal health [1]. About 90% of all required vitamin D for most people is synthesized in the skin in response to casual exposure to sunlight [2,3]. Vitamin D synthesis is essential for natural bone metabolism and calcium and phosphorous homeostasis [4,5], but it is also useful in the treatment of diseases such as rickets, psoriasis and eczema [6–8].

On the other hand, there is no doubt that excessive exposure to solar UV radiation is harmful and represents the major environmental risk factor for acute and chronic effects on the skin (skin cancers) [9–13], eyes [14,15] and the immune system [16,17], also accelerating skin aging [18,19]. Therefore, it is clear that whereas a moderate amount of UV exposure is beneficial, an excessive amount is detrimental [20].

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Erythema (sunburn) is the most familiar short-term symptom of normal human skin associated with UV radiation overexposure. It is represented by an acute skin inflammatory reaction with redness of the skin due to dilatation of superficial dermal blood vessels [1,18]. The erythemal reaction to UV may occur after different exposure times depending on the season: during summer in Mediterranean areas, UV radiation at midday can produce erythema in less than 20 min in a very sensitive phototype (skin type I), whereas during winter, several hours of sun exposure are required to induce erythema [21]. UV-induced erythema is a delayed response that follows an unperceivable UV effect activated through UV exposure and it reaches its maximum intensity between 6–8 and 24 h after exposure, depending on the dose [1,22]. This erythema fades after a day or longer, depending on the dose and skin type [23]. Estimates concerning the burden of disease due to sunburn are highly uncertain due to the paucity of good epidemiological data. However, there is now growing evidence that intermittent sun exposure, mainly from recreational activities, rather than cumulative or chronic occupational exposure, is associated with an increased risk of developing skin cancer, such as malignant melanoma [9,24,25]. Furthermore, the history of sunburn, especially severe sunburn episodes during childhood, may cause the development of skin cancers like melanomas on sun-exposed areas [9,18].

In recent years several measurements of the UV risk factor for human health have been developed. Erythema generally occurs once the threshold of the Minimal Erythemal Dose (MED, $J\,m^{-2}$) has been exceeded. This minimal dose, which causes a clearly perceptible or detectable biological reaction (erythema), varies depending on several factors, the most important of which is the skin type, with increasing MED values from skin type I (1MED = 200 $J\,m^{-2}$) to skin type VI (1MED = 1000 $J\,m^{-2}$). Because of the lack of a consistent baseline for MED measurement decreases for interstudy comparisons, about fifteen years ago a new concept independent from the skin type was proposed, the so-called Standard Erythemal Dose (SED) [26]. The SED is an erythemally weighted measure of effective radiant exposure: 1 SED = 100 $J\,m^{-2}$. Furthermore, an easy-to-understand measure of biologically effective UV radiation is the global solar UV index [27]. This is an internationally-agreed mechanism specifically designed to inform the public about UV levels, in the aim of promoting public awareness of the risks of UV exposure, and assisting local authorities in providing guidance on the level of sun protection to be used on any given day. Weather forecasts in many countries include a forecast of the solar UV index to guide public sun exposure. Biologically effective UV radiation at ground level has been investigated in various environments and conditions [11,15,28–33].

Besides the unperceivable UV effect, imperceptible by the human body, another important part of the electromagnetic sunlight spectrum is infrared radiation (IR), accounting for about 40% of the solar radiation that reaches the earth's surface. IR radiation is the main source of heat and IR rays produce heat upon exposure to the skin [34]. In this way people are able to immediately perceive the effect of solar radiation, at least in terms of thermal (dis)comfort. The heat effect of the absorbed radiation flux densities, both short- and long-wave radiations (both direct and reflected), by people exposed to outdoor conditions, is parameterized by a synthetic parameter, the outdoor mean radiant temperature (T_{mrt}). The T_{mrt} represents one of the most important meteorological parameters governing human energy balance and human thermal (dis)comfort [35], and several authors [36] have recently investigated the uncertainties in determining radiation fluxes and their impact for biometeorological purposes. T_{mrt} and other meteorological variables, such as air temperature, humidity and wind speed, represent the input parameters for the newly developed Universal Thermal Climate Index (UTCI) [37] which is the state-of-the-art of outdoor thermal (dis)comfort assessment. The UTCI was developed thanks to the efforts of the International Society of Biometeorology and the COST (a European program promoting Cooperation in Science and Technology) Action 730, with the cooperation of over 45 scientists from 23 countries [37]. The rational UTCI index is based on the most advanced multi-node model of human thermoregulation coupled with an adaptive clothing model. Therefore, the UTCI represents a universal solution (since appropriate for all major human biometeorological applications) for assessing the outdoor thermal conditions influencing humans. Despite the relatively recent availability (after 2009) of an official software code for the UTCI assessment, several new studies have been published which quantify outdoor thermal (dis)comfort and the potentiality of UTCI for environmental epidemiology [38–41]. Moreover, information from the UTCI, or other thermal indices, is also used in most European countries for developing efficient local public health emergency plans related to thermal discomfort conditions [42].

In this study the UTCI will be used for the first time to investigate whether perceived outdoor heat stress might represent a valuable proxy for the unperceivable effect of UV-induced risk of erythema in a Mediterranean city, Florence, Tuscany (Central Italy). The aim of this study is therefore to propose a real approach to link solar UV radiation and thermal factors by means of the application of two internationally recognized indices, in order to estimate their reciprocal interaction and the potential impact on human health. The strong association between outdoor heat stress and the UV-induced risk of erythema might be obvious during the warmest diurnal hours of the summer season, but what happens when sporadic heat stress conditions occur? How can the association between heat stress and biologically effective UV radiation vary when different hourly doses of SED are considered? Moreover, what happens when the coldest periods of the year, typically without heat stress, are considered? Since Florence is the most important Renaissance city in Europe and is visited during all periods of the year by millions of tourists from all over the world, all the analyses are detailed for different phototypes in this study.

2. Material and methods

2.1. Meteorological data

Meteorological data of air temperature (°C), relative humidity (%), wind speed ($m\,s^{-1}$), global radiation ($W\,m^{-2}$), atmospheric pressure (h Pa) and measurements of UVB solar radiation (280–320 nm) averaged over 15-min intervals, were obtained for the 2004–2012 period by a complete weather station within the framework of the LaMMA Consortium located in Sesto Fiorentino (43°82′ N, 11°20′ E, 40 m a.s.l.), a suburb of Florence, Tuscany (Central Italy). This monitoring station is managed by the Institute of Biometeorology of the National Research Council (IBIMET-CNR).

2.2. Biologically effective UV irradiance assessment

Continuous measurements of erythemally effective UV (UV_{Ery}) were performed from 2004 to 2012 by means of a broadband temperature-corrected radiometer with spectral response close to the erythemal action spectrum [43]. More specifically, the radiometer used was the UVB-501 (Solar Light CO., Philadelphia, USA). The calibration of the radiometer was periodically performed by using reference instruments (of the same type as the operational one) calibrated during intercomparison campaigns carried out in Switzerland [44] and Italy [45]. The UV_{Ery} is defined by the following equation:

$$UV_{Ery}(W\,m^{-2}) = \int_{UV} S(\lambda)A(\lambda)d\lambda$$