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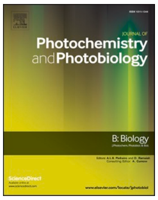

The potential role of UV and blue light from the sun, artificial lighting, and electronic devices in melanogenesis and oxidative stress

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ABSTRACT

Our exposure to blue light from artificial sources such as indoor lights (mainly light-emitting diodes [LEDs]) and electronic devices (e.g., smartphones, computer monitors, and television screens), has increased in recent years, particularly during the recent coronavirus disease 2019 lockdown. This radiation has been associated to skin damage across its potential in generating reactive oxygen species in both the epidermis and the dermis, skin water imbalances and of potential activating melanin production. These circumstances make it important to determine whether current blue light exposure levels under artificial illumination and electronic devices exposure can cause the previously indicated disorders as compared to solar UV and visible radiation in a typical summer day. Blue light accounted for 25% of the sun's rays, approximately 30% of radiation emitted by electronic devices, and approximately from 6% to 40% of that emitted by indoor lights. The reference equations showed that the sun was the main source of effective irradiance for immediate and persistent pigmentation as well as for potential oxidative stress in our skin. Effective blue light exposure to artificial devices is significantly lower than the solar contribution. However, its contribution must be considered as accumulative dose effect, and especially in people with hypersensitivity promoting skin hyperpigmentation.

1. Introduction

Overexposure to the sun is known to have harmful health effects, and while public awareness has increased, much remains to be improved in terms of sun protection behaviors.

It is well known that UVB and UVA rays from the sun are beneficial for human skin, although it is well known that solar UV overexposure can cause a range of skin and eye disorders [1,2].

Chromophores in the epidermis absorb approximately 70% of UVB radiation [3], causing immediate sun damage (sunburn or erythema) and triggering the production of melanin by melanocytes. Given its high energy levels, UVB radiation can also cause delayed sun-induced DNA damage [2]. UVA radiation reaches deeper layers of human skin with damage associated mainly to oxidative stress, as first step for photoageing, and promoting instant tan (Meirowsky phenomenon) by oxidation of existing melanin, followed by an immediate pigmentation for several hours [4,5]. The role of high-intensity visible light (380–500 nm) has been recently related to skin damage, so scientific community as well as photoprotection industry are going deeper in the analysis of blue light effect on human skin [6]. Some authors have shown that stimulation with light in the visible spectrum ranging from 415 to 465 nm (violet-blue light) can cause hyperpigmentation (melasma), mediated by opsin3, a protein that regulates melanin production related to the persistent pigment darkening, considered UVA depending until now [7]. Blue light below 453 nm has been also described to induce oxidative stress in a range equivalent to just 25% of that caused by UVA irradiation [8].

The fact that we are increasingly exposed to artificial blue light from electronic devices and indoor lighting (mostly LED) led us to wonder whether current doses might be capable of causing skin pigmentation disorders [6,7,9]. This is a particularly relevant at present due to COVID-19 pandemic, where strict lockdown measures implemented for virus control. Millions of people have been exposed to minimal sunlight but to potentially high doses of artificial light from digital screens and lighting.

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The question is whether doses received during this time might be sufficient to cause oxidative stress and pigmentation disorders, and if so, how each source of light contributes to these biological effects. For that, we have analyzed the emission spectra and irradiances of blue and UV light emitted by the sun over a diurnal cycle and by different sources of artificial light, including smartphones, tablets, computer monitors, and television screens. Quantification of absolute spectral irradiance at normal distance of devices, allows to us to quantify the extent to which spectrally weighted irradiance from each source contributed to three biological effects: immediate pigment darkening (IPD), persistent pigment darkening (PPD), and oxidative stress and compare to sun exposure during a summer day cycle.

2. Materials and Methods

We measured the emission spectra and irradiances of the sun in a middle summer day cycle and the irradiance and spectral characteristics of artificial illumination as well as the monitors of different electronic devices: One incandescent bulb (Philips 60 W lamp), 1 compact fluorescent lamp (Lexman 22 W), 1 fluorescent tube (Osram 18 W, 60 cm), 3 LEDs lamps (Philips Coreplus A60 Led 10 W) of three different color temperatures (3000, 6000 and 6500 K); 3 tablets (BQ Kepler 2, Lenovo M10, Samsung Galaxy Tab A); 5 cell phones (Xiaomi Mi Max 3, BQ Aquarius X, Huawei P Smart, Motorola C Plus, and Iphone 7), 4 computer screens (Huaweii Matebook D, ASUS GA401IU-HE002, BenQ

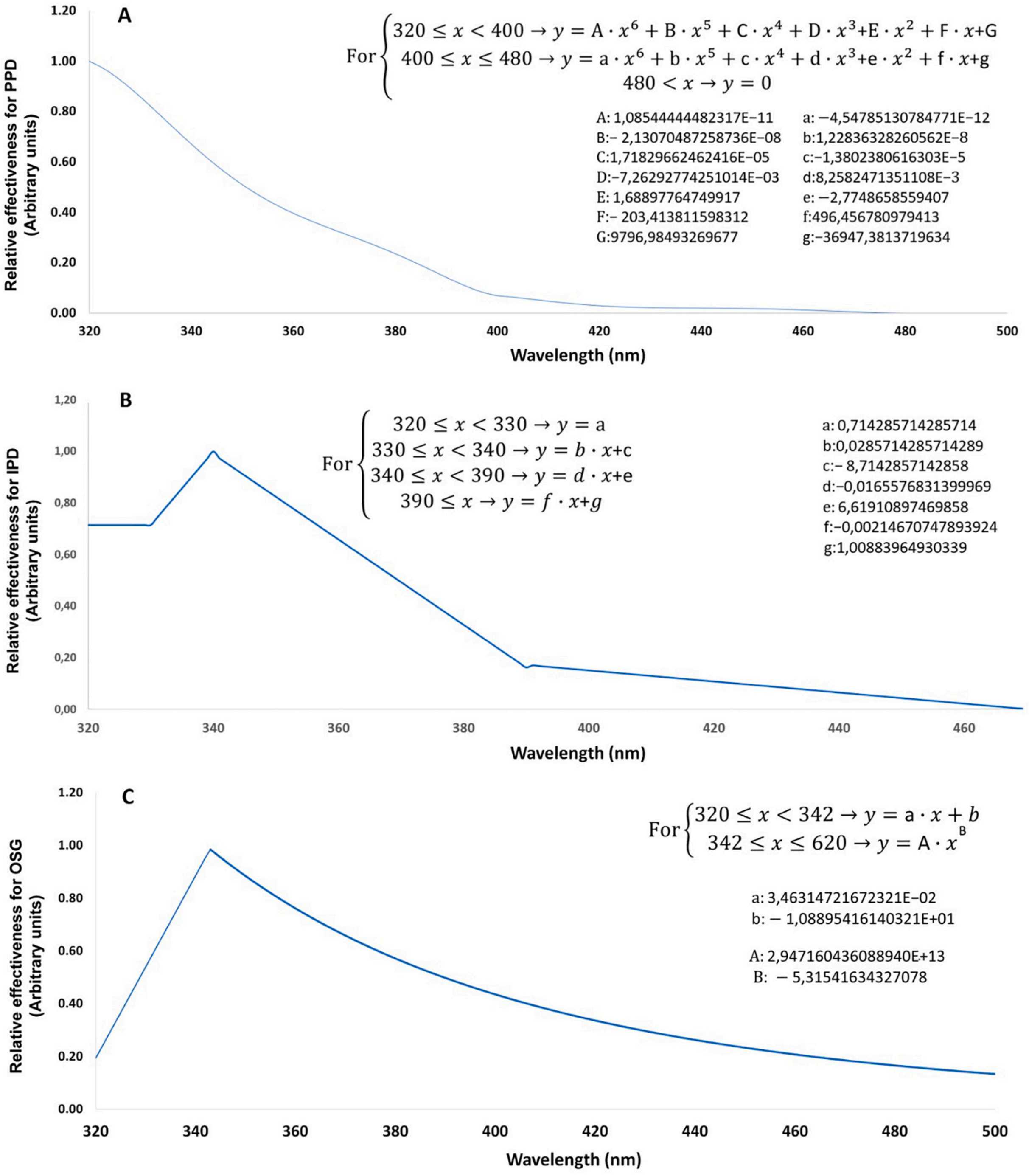

Fig. 1. Weighted regression curves in terms of relative effectiveness for A) PPD: persistent pigmentation (range 320–500 nm) [13], B) IPD: immediate pigmentation (range 320–470 nm) [14,15] and C), generation of oxidative stress (range 320–620 nm) [16].

2706PQ and HP 1943HR) and a LED smart TV (LG 75UM7050). All measurements were made in the Photobiology Laboratory of the Medical Health Research Center at the University of Malaga in Malaga, Spain.

Daylight was measured from the roof of the study center (36.72° N. 4.47° W, 50 m above sea level) on July 2nd, 2019, just corresponding to days of maxima sun irradiance of the year in our latitude. The measurements were made hourly from 9:00 to 15:00 and covered a spectral range from 300 to 800 nm.

The light-emitting devices were turned on for 10 min to allow stability of radiation emission and the screens were set to a white background with maximum brightness. For spectral characterization of lamps and electronic devices, light sensor was situated at 0 cm for cell phones, tablets and light sources while monitor screens were measured at 20 cm. For calculations of irradiance of the devices under normal life conditions, the monitor screens were measured at 60 cm following the European standard of safe exposure [11], 150 cm for light sources [6,10–12], and 20 cm for mobile devices (mean distance of screen interaction to our face).

Spectral irradiance was measured using a MACAM SR-2271 double monochromator spectroradiometer (Irradian Co., Scotland, UK) fitted with an Ulbricht sphere via a fiber optic cable. The spectroradiometer was wavelength- and irradiance-calibrated against a certified UV–visible calibration lamp at the Spanish National Optics Center.

For each light source, five measurements were taken from the predefined distances to calculate spectral irradiance under normal exposure conditions. Irradiance values were expressed as means and standard deviation, which was less than 2% in all cases.

Absolute spectral irradiance values for daylight and the different light sources were weighted by wavelength to estimate the associated biological effects corresponding to IPD, PPD, and oxidative stress. For

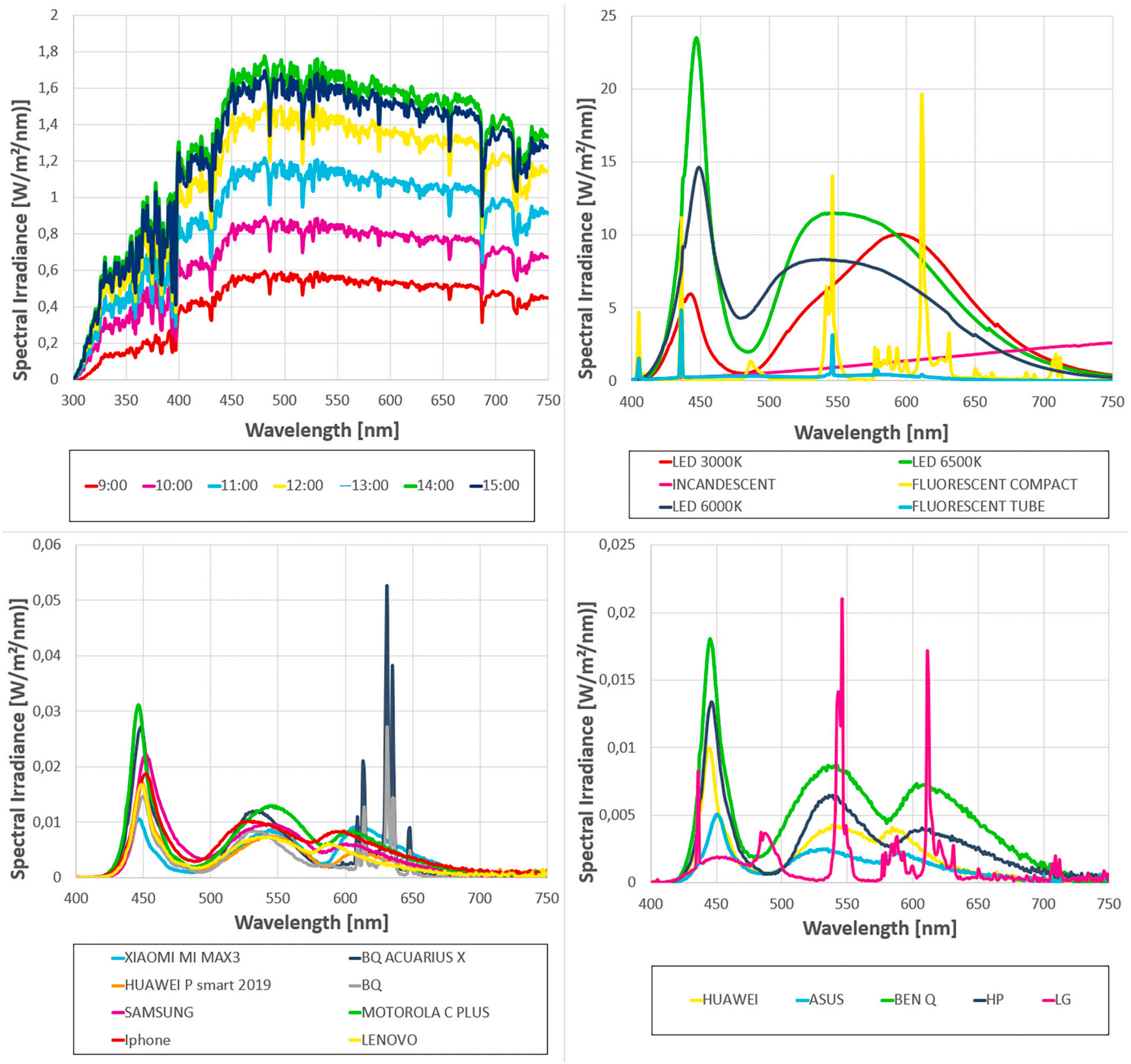

Fig. 2. Emission spectra of the light sources analyzed. A), spectral irradiance of the sun on July 2nd, 2019 from 9:00 to 15:00, B), spectral irradiance of visible lamps C), spectral irradiance of cell phones and tablets. D), spectral irradiance of monitors and TV.

calculations of the biological effective irradiance of different light sources with respect to PPD; the action spectra proposed by Maeda et al. was used since it covers a range from 320 to 500 nm [13]. The weighted irradiance curve was estimated by regression adjustments from the figure of the original work. Polynomial and potential adjustments were estimated by least squares and with coefficients of determination over 0.975. Finally, the relative data at 1 nm intervals were calculated taking the value of 1 at the maximum efficacy of the biological effect at 320 nm. In case of the IPD action spectrum we proceed in the same manner (Fig. 1). In this case we combined 2 action spectrums in order to reach wavelengths up to 470 nm, covering the blue region of the solar spectrum; Rosen et al. in 1990 and Irwin et al. 1993 [14,15]. In case of generation of oxidative stress, we used the action spectrum described by Zastrow in 2009 [16].

From effective biological pondered spectra for different illumination devices as well as sun radiation, we developed three reference equations to estimate the received doses associated with the effects of IPD, PPD and oxidative stress in our normal day life. Thus, exposure under sun outdoor is combined with exposure to artificial light and the different electronic devices and percentage of contribution of each illumination source can be predicted for the total exposure dose. For calculations of total effective dose for the different biological effects, the constants corresponding to each variable of equation have been included as the average effective irradiance by type of device (monitors, interior lights, smartphones/tablets and sun) at the standard distance, and we have defined an average exposure time (Formulas (1)–(3)). As example for formula calculations in case of specific situations (hour under solar exposure, specific type of indoor lighting and electronic device, as well as exposure time desired), 4 different situations have been calculated for PPD effective dose (Formula (1)).

3. Results

The emission spectra for the different light sources are shown in Fig. 2. In the case of indoor lighting, there was a clear tendency towards the use of light-emitting diode (LED) technology, evidenced by the repeated presence of the characteristic LED radiation pattern, with a peak in the blue light range (around 450 nm). The contribution of blue light emitted by the sun (400–500 nm) was several orders of magnitude greater than contributions from other sources (Table 1).

Based on the emission spectra identified for each artificial light source, we classified the irradiated energy into three ranges: blue (400–500 nm), green (500–600 nm), and red (600–750 nm). We added the UVA part of the solar spectrum due to its high relative weight in the action spectra for pigmentation and oxidative stress. These results are shown in Table 1.

In the case of smartphones, blue light accounted for a mean of 32.3% of the visible light spectrum, with contributions ranging from a minimum of 19.1% (Xiaomi) to a maximum of 39.82% (iPhone). In the case of the computer monitors, blue light accounted for a mean of 30.5%. The results for the artificial lights were more variable and ranged from 6.12% for incandescent lights to 36.81% for fluorescent bulbs. The percentage of daylight in the blue light range was similar throughout the solar cycle analyzed (25.38–26.07%).

Regression analysis of the weighting curves for the three biological effects—IPD, PPD, and oxidative stress by wavelength resulted in the functions shown in Fig. 1.

Since skin pigmentation as well as oxidative stress is mostly depending on UVA radiation, sun exposure in a typical summer day was able to generate approximately 98% of potential damage. Effective irradiance for PPD under sun at 14:00 midday (12:00 solar hour) was able to promote 2549 mW/cm^2 followed by Fluorescent tube at 1.5 m distance (standard illumination distance) with 0,0018 mW/cm^2. Electronic devices at 20 cm or computer screens varied from 0.00004 to

Table 1
Real (unweighted) irradiance in the visible light range (400–750 nm) for computer monitors at a distance of 60 cm, bulbs at a distance of 150 cm (office illumination 500 lx), mobile devices at a distance of 20 cm, and the sun at a distance of 50 m above sea level for the range of 320–750 nm (UVA-visible light spectrum), distributed into UVA, blue, green, and red light.

Device/time	Total irradiance (mW/cm^2)	% UVA (320–400 nm)	% Blue (400–500 nm)	% Green (500–600 nm)	% Red (600–750 nm)
Sun. July 2nd, 2019					
9:00	19.021	7.13	26.07	28.67	38.12
10:00	29.449	9.64	25.38	27.89	37.09
11:00	40.094	9.64	25.38	27.89	37.09
12:00	49.921	9.64	25.38	27.89	37.09
13:00	55.940	9.64	25.38	27.89	37.09
14:00	58.457	9.64	25.38	27.89	37.09
15:00	55.780	9.64	25.38	27.89	37.09
Lamps					
Incandescent bulb	0.575	–	6.12	21.5	72.39
Compact fluorescent lamp	0.274	0.51	11.47	38.55	49.47
Fluorescent tube	0.313	2.25	35.81	42.14	19.80
LED 3000K	0.281	–	11.99	47.27	40.74
LED 6000K	0.308	–	30.84	46.84	22.32
LED 6500K	0.309	–	28.32	46.31	25.38
Cell phones and Tablets					
XIAOMI MI MAX3	0.028	–	19.1	39.34	41.56
BQ ACUARIUS X	0.022	–	31.07	37.37	31.57
HUAWEI P smart	0.019	–	29.95	36.68	33.37
MOTOROLA C+ PLUS	0.021	–	36.71	46.68	16.6
iPhone 7	0.010	–	39.82	51.76	8.42
BQ Tablet	0.033	–	32.2	39.49	28.31
LENOVO Tablet	0.051	–	34.4	48.9	16.7
SAMSUNG Tablet	0.015	–	35.4	39.25	25.35
Computer screens and TV					
HUAWEI Matebook	0.019	–	28.4	42.41	29.19
ASUS	0.010	–	33.3	47.21	19.49
BQ 2706PQ	0.061	–	29.68	41.58	28.74
HP 1943HR	0.029	–	33.25	43.61	23.15
LED TV LG 75UM7050	0.014	–	27.74	33.13	39.13

0.0003 mW/cm^2 of PPD effective irradiance.

4. Discussion

Exposure to short-wavelength light (415–465 nm, violet-blue) contributes to photoaging and skin hyperpigmentation in melanocompetent individuals [7,17]. The shorter the wavelength, the greater the contribution. It is assumed that exposure to light at a wavelength of above 480 nm will have no effect.

The extensive use of electronic devices and LED lighting, combined with time spent outdoors, means that we are exposed to very high doses of blue light on a daily basis. Exposure to artificial sources was intensified during the COVID-19 lockdown, which lasted for several months in different countries.

Blue light is found in most everyday light sources. However, not all these sources contain the same proportion of blue light in their spectrum, nor do they emit with the same intensity and the blue light hazard related to these artificial devices has been deeply analyzed in human eye [18,19], but not related to human skin.

LED technology generates white light from blue LEDS coated with phosphor [18] causing the characteristic blue peak seen in LED lights. This peak reflects the increase in energy produced in this wavelength range. However, by simply multiplying total irradiance by the proportion of blue light, we can see that warm LED lights (≤3000 K) emit the same or slightly less radiation in this range to achieve similar illuminance (lux) to traditional incandescent bulbs because they have a much higher energy efficiency (lumens/watt). Traditional bulbs therefore require much more energy than LEDs, meaning higher irradiances that are not compensated for by the lower proportion of radiation in this wavelength range. LEDs are used for outdoor and indoor lighting, mobile devices, vehicle headlights, tablets, laptops, televisions, etc.

Changing lifestyle habits, often characterized by many hours spent in front of digital screens, often in indoor spaces illuminated by cold light (>5000 K), has resulted in increasing exposure to blue light [19]. To estimate the effective irradiance associated with the PPD phenomenon, we developed the following reference equation based on the mean effective doses by type of source (Formula (1)).

$$D = (a \bullet h_1 + b \bullet h_2 + c \bullet h_3 + d \bullet h_4) \bullet {}^{3600}\!/\!_{1000} \tag{1}$$

Where:

D: Dose of blue light [J/cm^2] received in the diurnal cycle analyzed

a: 0.000122175mW/cm^2 (mean irradiance at 400-500 nm, computer monitors)

b: 0.000825764mW/cm^2 (mean irradiance at 400-500 nm, indoor lights)

c: 0.000114033mW/cm^2 (mean irradiance at 400-500nm, smartphones/tablets)

d: 1.891968012mW/cm^2 (mean irradiance at 320-500 nm, sun)

h1: Estimated hours a day in front of a monitor

h2: Estimated hours a day exposed to artificial indoor lighting

h3: Estimated hours a day using a smartphone/tablet

h4: Estimated hours a day exposed to the sun

Certain factors should be taken into account when applying our equation. First, the irradiance doses are based on mean values calculated from a sample of commonly used everyday electronic devices and bulbs. Second, solar radiation varies considerably throughout the day and seasonally (Table 2).

The sun is thus the greatest contributor to the biological effects analyzed since the high contribution of UVA and high energy visible radiation for the studied biological effects, 2300 times greater than that emitted by the next largest contributor. Without sunlight exposure, it last very long time to get effective damage for skin pigmentation by artificial lighting and electronic devices exposures in a normal day life.

Table 2
Effective irradiance of sun and different illumination devices at real-life time and distance.

Device	Distance (cm)	Effective irradiance for PPD (mW/cm^2)	Effective irradiance for IPD (mW/cm^2)	Effective irradiance for oxidative stress (mW/cm^2)
Sun. July 2nd, 2019				
9:00	50 m above sea level	0.6126	0.9306	3.353
10:00	50 m	1.2843	1.8662	5.739
11:00	50 m	1.7485	2.5407	7.814
12:00	50 m	2.177	3.1634	9.729
13:00	50 m	2.4395	3.5449	10.902
14:00	50 m	2.5493	3.7044	11.393
15:00	50 m	2.4325	3.5347	10.871
Lamps				
Incandescent bulb	150	0.0004	0.00115	0.024
Compact fluorescent lamp	150	0.0006	0.00182	0.025
Fluorescent tube	150	0.0018	0.00511	0.051
LED 3000 K	150	0.0006	0.00175	0.026
LED 6000 K	150	0.0012	0.00327	0.044
LED 6500 K	150	0.0014	0.00371	0.042
Cell phones and tablets				
XIAOMI MI MAX3	20	0.0001	0.0002	0.003
BQ ACUARIUS X	20	0.0001	0.0003	0.003
HUAWEI P Smart	20	0.0001	0.0002	0.002
BQ tablet	20	0.0002	0.0004	0.004
SAMSUNG	20	0.0001	0.0002	0.002
iPhone 7	20	0.0001	0.0001	0.001
MOTOROLA C +	20	0.0001	0.0003	0.003
LENOVO tablet	20	0.0002	0.0006	0.008
Computer screens				
HUAWEI	60	0.0001	0.0003	0.003
ASUS	60	0.00005	0.0001	0.002
BEN Q	60	0.0003	0.0008	0.009
HP	60	0.0002	0.0004	0.004
LG	60	0.00004	0.0001	0.002

In the Table 3 it has been included the calculations using the reference Eq. (1) taking into account the constants corresponding to each variable of equation as the average effective irradiance by type of device (monitors, interior lights, smartphones/tablets and sun) at the standard distance, and we have defined an average exposure time. if we assume that an office worker on a typical day uses a smartphone/tablet for 1.5 h [20], is exposed to artificial lighting and monitors for 8 h, and spends 1 h in the sun, he/she will be exposed to 6.84 J/cm^2 effectives of blue light, of which the sun would account for 99.59%, artificial lighting for 0.35%, monitors for 0.05%, and mobile devices for 0.01%.

Therefore, data reflects the control variable for blue light effective dose in normal living situation as around 99% of the total effective dose. Electronic devices as well as indoor lighting represent around 1–2% of all the PPD effective dose. As example of specific exposure (instead of average values by type of light condition), 4 situations, considering specific electronic devices and exposure time, as well as specific indoor lighting lamp and sun exposure at different hours of a normal summer day are shown in Table 3. If we compare the results obtained by considering the average exposure irradiances by type of source indicated above, with those resulting from the analysis of specific exposure situations (Table 3), we can confirm that for a usual daily cycle in any case the controlling source is solar radiation, and that the maximum dispersion is less than 0.8% in the case of indoor-light, 0.01% in the case of cell phones and tablets, 0.2% in the case of screens and 0.1% in the

Table 3

Example of 4 situations of exposure to solar radiation and specific devices and the average of effective irradiance for PPD by type of source (indoor lighting, screens, cell phones/tablets and sun) in terms of effective doses for PPD. Data are obtained from the Formula (3).

		PPD				
		Effective irradiance	Exposition time	Dose	Contribution	$DOSE_{TOTAL}$
		(mW/cm^2)	(h)	(J/cm^2)	%	
Situation 1	Indoor-light (LED 6000 K)	0.00122	8	0.0352	0.75%	4.6671
	Cell phone (BQ Acuarius X)	0.00011	1.5	0.0006	0.01%	
	Screen (BQ)	0.00028	8	0.0079	0.17%	
	Sun (10:00, South Spain, 2ndJul)	1.28429	1	4.6234	99.06%	
Situation 2	Indoor-light (LED 6000 K)	0.00122	8	0.0352	0.38%	9.2212
	Cell phone (BQ Acuarius X)	0.00011	1.5	0.0006	0.01%	
	Screen (BQ)	0.00028	8	0.0079	0.09%	
	Sun (14:00, South Spain, 2ndJul)	2.54931	1	9.1775	99.53%	
Situation 3	Indoor-light (Fluorescent)	0.00179	8	0.0516	1.10%	4.6764
	Cell phone (Iphone)	0.00005	1.5	0.0003	0.01%	
	Screen (LG)	0.00004	8	0.0012	0.03%	
	Sun (10:00, South Spain, 2ndJul)	1.28429	1	4.6234	98.87%	
Situation 4	Indoor-light (Fluorescent)	0.00179	8	0.0516	0.56%	9.2305
	Cell phone (Iphone)	0.00005	1.5	0.0003	0.00%	
	Screen (LG)	0.00004	8	0.0012	0.01%	
	Sun (14:00, South Spain, 2ndJul)	2.54931	1	9.1775	99.43%	
Average exposure	Indoor-light (Average)	0.00083	8	0.0238	0.35%	6.8390
	Cell phone (Average)	0.00011	1.5	0.0006	0.01%	
	Screen (Average)	0.00012	8	0.0035	0.05%	
	Sun (Average, South Spain, 2ndJul)	1.89197	1	6.8111	99.59%	

Finally, the potential total effective dose for PPD generation from average data of each type of electronic device, indoor lighting and average solar exposure in a normal summer day cycle is also shown.

case of solar radiation, which allows us to assume average values as valid for model construction, in addition of considering the fact that throughout the day we are exposed to different light sources.

We also developed a reference equation using the mean effective doses by type of source for inducing IPD to determine the contribution of each light source to our daily dose of blue light (Formula (2)).

$$D = (A\bullet h_1 + B\bullet h_2 + C\bullet h_3 + E\bullet h_4)\bullet {}^{3600}\!/_{1000} \qquad (2)$$

Where:

D: Dose of blue light [J/cm^2] received in the diurnal cycle analyzed

A: 0.000330675 mW/cm^2 (mean irradiance at 400-470 nm, computer monitors)

B: 0.002295893 mW/cm^2 (mean irradiance at 400-470 nm, bulbs)

C: 0.000287042 mW/cm^2 (mean irradiance at 400-470 nm, smartphones/tablets)

E: 2.754992465 mW/cm^2 (mean irradiance at 320-470 nm, sun)

h1: Estimated hours a day in front of a monitor

h2: Estimated hours a day exposed to artificial indoor lighting

h3: Estimated hours a day using a smartphone/tablet

h4: Estimated hours a day exposed to the sun

The same caveats as those applied to the PPD equation should be taken into account for the above equation. Constans for each variable are again results of the average effective irradiance of different artificial devices and average irradiance of a daily cycle under solar radiation.

In this case, the proportion of blue light emitted by the sun was 1200 times greater than that emitted by the next largest contributor. Again, in the absence of sunlight (or laboratory experiments), it would be very difficult to reach a dose capable of inducing minimal perceptible immediate pigmentation.

In this case, and taking into account the average values under each type of light device, a typical office worker using a smartphone or tablet for 1.5 h and spending 8 h in the office and 1 h in the sun would receive a dose of 10 J/cm^2, of which 99.22% would be contributed by the sun, 0.66% by office lighting, 0.10% by monitors, and 0.02% by smartphones/tablets. Analysis considerations according to material and method specifications for calculations of irradiance of the devices under normal life conditions.

Finally, we developed a reference equation using the mean effective irradiances by type of source for inducing oxidative stress and so determine the contribution of each light source to this effect (Formula (3)).

$$OSG = (f\bullet h_1 + g\bullet h_2 + j\bullet h_3 + k\bullet h_4)\bullet {}^{3600}\!/_{1000} \qquad (3)$$

Where:

OSG: free radicals [rad/mg×10^12] formed in the diurnal cycle analyzed

f: 0.003821552 mW/cm^2 (mean irradiance at 400-620 nm, computer monitors)

g: 0.036006292 mW/cm^2 (mean irradiance at 400-620 nm, bulbs)

j: 0.0036220939 mW/cm^2 (mean irradiance at 400-620 nm, smartphones/tablets)

k: 8.543518522 mW/cm^2 (mean irradiance at 320-620 nm, sun)

h1: Estimated hours a day in front of a monitor

h2: Estimated hours a day exposed to artificial indoor lighting

h3: Estimated hours a day using a smartphone/tablet

h4: Estimated hours a day exposed to the sun

The same caveats as those applied to the PPD and IPD equations should be taken into account for the above equation.

Again, and taking into account the average values under each type of light device a typical office worker using a smartphone or tablet for 1.5 h and spending 8 h in the office and 1 h in the sun would form 32,099 radicals/mg × 10^12, of which 95.82% would be contributed by the sun, 3.23% by office lighting, 0.34% by monitors, and 0.61% by smartphones/tablets. Analysis considerations according to material and method specifications for calculations of irradiance of the devices under normal life conditions.

As above, the formula can be adapted to estimate the production of free radicals in different circumstances. Again, the highest contributor in normal circumstances will always be the sun, with a contribution of over 95%.

5. Conclusions

Exposure to blue light has health consequences, including photoaging and hyperpigmentation. LED technology is being increasingly used to provide both indoor and outdoor lighting and it emits a considerable proportion of blue light. The effective irradiance for PPD, IPD and oxidative stress emitted by sun and the different artificial light devices calculated for an office worker show that the contribution of sources other than the sun to the effects of PPD and IPD is less than 1% and less than 5% for the case of oxidative stress. Despite the low effective irradiance emitted by electronic devices and artificial light compared to solar radiation, that could lead to think no photodamaging effect of artificial devices, we must consider that the responses of the skin are a consequence of the integration of all daily exposure to light and all sources of radiation. Blue lights are potentially harmful to our skin in the long terms. In any case, in the absence of sunlight, artificial sources lack the potential to induce photodamage to the skin under normal use conditions, with the exception of photosensitive patients as well as high skin phototypes. These people must protect themselves when exposed to sources of blue light.

The limitations of the study are that the reference equations are developed taking average effective values by type of biological effect and type of device. The action spectra used for the study present also limitations: Maeda's spectrum of action for PPD was obtained from tests on normal Japanese individuals with limit at 480 nm. Irwin's action spectrum for IPD was obtained from a sample census of male and female subjects between 18 and 42 years old with Fitzpatrick types III, IV and V. The Zastrow action spectrum was obtained from human skin biopsies Fitzpatrick II type. The detailed use of these reference equations is for a typical daily cycle.

The field of pigmentation and oxidative stress is dynamic and in permanent evolution, new studies may require the revision of the action spectra considered and consequently the edition of the proposed equations.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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