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Research Article

Sun-protective Properties of Technical Sportswear Fabrics 100% Polyester: The Influence of Moisture and Sweat on Protection against Different Biological Effects of Ultraviolet (UV) Radiation

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ABSTRACT

The use of technical sportswear is now widespread, but the degree of protection these fabrics offer against UV radiation is not known. We have analyzed the capacity of different types of technical sportswear fabrics to protect against different UV biological effects. A sample of 34 100% polyester t-shirts from different manufactures was classified by color, fabric structure, cover factor, and due to different tonalities, dark, and clear color. Ultraviolet protection factor was calculated according to UNE-EN13758. The protection factor for other biological effects as pre-vitamin D_3 production, non-melanoma skin cancer, photoimmunosuppression, and photoaging was analyzed. The effects of moisture and sweat in protection were also evaluated. From the analyzed sample garments, more than 75% achieved an excellent protection value (protection factor 40–50+). Higher values were found in double-layer type ($P < 0.05$). Cover factor was the main determinant of biological protection factors with correlation coefficients of 0.81 for UPF (erythema), 0.77 for NMSC, and 0.63 for photoimmunosuppression. Water or sweat humidity saturation increased biological protection factors over a 20% ($P < 0.05$). The 83% of the fabrics analyzed showed less than 5% of transmittance with labeling as UVA protective elements. No effect of fabric color was found related to biological protection factors. The 100% polyester sports T-shirts of the analyzed sample offer general protection against UV for different biological effects that can be increased by humidity but no affected by fabric color.

INTRODUCTION

Sufficient awareness about the harmful effects of prolonged sun exposure is generally lacking, particularly among young sport people (1,2). Exposure to UV radiation from the sun without adequate protection is the strongest risk factor for melanoma and non-melanoma skin cancers. Professional and amateur athletes spend a lot of time outdoors during times of peak radiation (*e.g.*, periods of warm weather and between 10:00 and 16:00), and many of them have been doing this since they were children as well as people under immunosuppression treatments (3,4). They are thus particularly vulnerable to the effects of UV radiation. Achieving full sun protection in this population is a key social objective, and the World Health Organization recommends using sunscreen and wearing sunglasses, a hat, and other protective clothing as a first line of defense. As second line of defense, intake of antioxidants that prevents potential oxidative damage is also recommend (5) (although its effectiveness in animals has been demonstrated, in the case of humans it still requires more level of evidence). The growing demand for sun-protective clothing among athletes has generated new lines of work and research in the textile industry aimed at identifying new fibers and combinations of dyes, detergents, and finishing products that offer high levels of protection (6,7). The methods for testing, evaluating, and marking sun-protective clothing in Europe are specified in the standards EN 13758–1:2001 + A1:2006 and EN 13758–2:2003 + A1:2006 (8–10). A fabric's UV protection factor (UPF) of a fabric is the quantification factor for its photoprotection potential in preventing erythema on skin. Its value is determined as the ratio between the effective spectrum of the erythema calculated as product of CIE erythema action spectrum and the emission spectrum of the source, and the same effective spectrum of the erythema affected by the transmittance of the garment. Erythema has been considered as reference effect due to different reasons: it is an easy method to produce, easy to measure, cheap, with a well-defined associated action spectrum and known dose values for each type of Fitzpatrick skin. However, in spite the existence of this official standard for fabric photoprotection based on erythemal effect on human skin, a series of different biological effects take place in the skin after exposure to solar radiation that need to be considered for the complete evaluation of the photoprotection offered by fabrics, with special emphasis on UVA protection. Recently, photoprotection level of different tools as sunscreen is adapting claims related to other biological effects as photoimmunesupression,

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oxidative stress production, photoaging or non melanoma skin cancer production related to both UVB and UVA parts of the UV spectrum. Chronic effects include photoaging and skin cancer. Based on the well-known action spectra for those biological effects, different biological protection factors for the fabric can be calculated and in a previous work for different types of fabrics (11). To guarantee a good level of photoprotection of a garment in accordance with the indicated standards, the value of the UPF parameter determined as indicated must be at least 40. Untested garments, by contrast, offer no guarantees, as despite their appearance, they might not have sufficient properties to block potentially harmful levels of radiation (12). UPF can be affected by a range of factors, such as stretching, moisture, and wash and wear (13). For different types of fabric typically used in summer clothing (11), the main conclusion was that it is necessary to point out the importance of analyzing the range of fabrics used in outdoor clothing and informing consumers about their properties due to the high variability of protection factors. Desirable properties of sportswear include comfort, elasticity, lightness, ease of washing, hypoallergenic, and high breathability (14).

The polyester technical fabrics are functional materials made of very fine threads (10 000 threads g^{-1}) 100% single- or double-layer polyester designed for sports and other uses. This material has the properties listed above.

Although the value of UPF is fundamentally dependent on the transmittance in the UVB spectrum band, it is important, not least the transmittance in the UVA band, especially in photosensitive patients, where most of the photosensitive lesions are caused by this region of the spectrum. Even small doses can cause acute reactions. Therefore, a low transmittance value in the UVA range is also desirable for this type of garment (2).

The risk of skin damage increases at latitudes close to the equator, where the irradiance values are maximum, and consequently the UV doses received for the same periods of exposure are also maximum (15). In these circumstances, training sessions that require long periods of exposure, involve extreme exposure, and a significant increase in the risk of skin lesions (16). In latitudes corresponding to the center and south of Spain, in summer, at noon, ultraviolet index values over 9 are recorded (17,18), which also require consideration. So, sportswear, and particularly that designed for outdoor use, must provide effective protection.

The aim of this study was first, to analyze the degree of protection offered by 100% polyester technical fabrics against UV radiation and in relation to different biological effects on the skin. The fabric cover factor, as the percentage area occupied by fibers, aspect that depends on its structure and finishing treatments, has been correlated to the different biological protection factors as well as the effect of the humidity in the case of water or sweat as well as the effect of the fabric color.

MATERIALS AND METHODS

A sample of 34 randomly selected 100% polyester technical t-shirts of different brands, colors, and types of wefts from those available in the different market outlets was taken as a sample census. Among the brands of the selected garments are Gric, Aqua royal tecnic, Bike 55, Inverse, R run & pro, Roly, Puma, Adidas, and Kalenji. Microscopical observations of fabrics, textures, and their structure due to similar fabrication procedures allow to classify the sample set according to the type of structure: single-layer, single-layer optical brightener, double-layer elastic perforated simple, double-layer elastic perforated double, and double-layer nonelastic perforated (Table 1).

The spectral transmittance of all the garments of our sample census in the range 290 nm to 400 nm was determined. An Oriel 300 W solar simulator (Newport Co., Irvine, CA) and a MACAM SR-2271 double monochromator spectroradiometer (Irradian Co., Scotland, UK) connected by fiber optic cable to an UV sensor type Ulbricht integrating sphere were used, equipment calibrated annually both in wavelength and irradiance at the National Metrology Center of Spain against certified UV–Visible calibration lamp. Direct measurement of the solar simulator radiation was made and subsequently with interposition of each of the fabric samples belonging to each of the garments in our study. Each sample was evenly distributed and unstretched on the integrating sphere sensor and illuminated by the solar simulator. The distance between the solar simulator and the integrating sphere sensor was 10 cm.

UPF values were calculated as per EN 13758–1:2001 + A1:2006

$$\mathrm{UPF} = \frac{\int_{290}^{400} E(\lambda) \times \epsilon(\lambda)\mathrm{d}\lambda}{\int_{290}^{400} E(\lambda) \times \epsilon(\lambda) \times T(\lambda)\mathrm{d}\lambda} \quad (1)$$

where E is spectral irradiance; ϵ, relative erythemal action spectrum (19); and T, transmittance of the fabric.

The final UPF for each fabric type was calculated as the lower limit of the 95% confidence interval computed using the t-distribution for the mean of five samples. Each of those five samples corresponded to the mean value of transmittance of 10 different part of the T-shirt:

$$\mathrm{UPF} = \overline{\mathrm{UPF}} - t_{\propto/2;n-1} \bullet \frac{s}{\sqrt{n}} \quad (2)$$

where UPF is the ultraviolet protection for each type of fabric; $\overline{\mathrm{UPF}}$ is the mean UPF value for a sample of n elements; $t_{\propto/2;n-1}$ is the t-distribution value for a 95% confidence interval for a sample of $n-1$ elements; s is the standard deviation for n elements; and n is the number of elements in the sample. So, following the standard, the final UPF is the lowest UPF found into the confidence interval.

Three UPF categories were created in accordance with the EN 13758-2 (2003 + A1:2006) standard on sun-protective clothing (9): excellent (40–50+), very good (25–39), and good (15–24). A UPF of <15 was considered to afford low protection.

As UPF is based on the erythemal effect of UV radiation, mainly due to the UVB part of the UV spectrum, recently, other biological effects, which wavelengths responsible are also UVA depending. Skin oxidative stress, immediate pigmentation, or the UV biological effect on photoimmunesupression are actually of interest in dermatology and their action spectra are clearly defined. So, we include those effects for a broader photoprotection potential of the sport fabrics.

The procedure of calculations is the applied to obtain the UPF factor (referred to erythema) of the technical fabrics analyzed. So equivalent factors were determined referring to the different effects contemplated in our study. For each biological effect, the protection factor is calculated by the ratio of the integral from 290 to 400 nm of the reference solar spectrum irradiance convoluted by the relative value of corresponding to the action spectrum (ranging from 0–1) divided by the solar spectrum irradiance convoluted by the action spectrum and the transmittance of the fabric at that wavelength (see Formula (1)). The action spectra selected were that of previtamin D_3 production (20), NMSC (21), photoimmunesupression (22), and photoaging (23).

Cover factor was determined by analyzing magnified images of the fabrics analyzed. Each sample was analyzed under a Nikon Eclipse E-400 optical microscope with a magnification of ×40 and a fully open diaphragm and iris. Grayscale images of each sample were captured on a Polaroid DMC1 digital microscope camera attached to the ocular lens of the microscope (Fig. 1). These were then processed using Visilog software (v 6.3, Noesis, France), which assigns each pixel a grayscale value between 0 (ideal black) and 255 (ideal white). The cover factor (area occupied by fibers) was calculated as the percentage of open areas relative to fabric; areas with pixels values over 155 were considered to be space. The cover factor percentage was calculated by subtracting the open space percentage from 100%. The final percentage was calculated as the mean of 10 measurements from different areas of each of the five fabric samples.

A correlation study was carried out between the different biological factors studied and cover factor and between the UPF factor and UVA transmittance.

Table 1. UPF and protection values for different biological effects associated with UV radiation according to cover factor, color, and number of washes. UVA transmittance and protection rating according to the EN 13758–2 (2003 + A1:2006) standard are also shown.

Color	Lightness (L^*)	Fabric type	Washes No.	Cover factor %	UPF	Vit D_3	NMSC	PHINM	PHAG	UVA (% Transmittance)	Protection rating
White	89	Single-layer	0–15	60	14	17	14	12	10	9.8	Low
White	78		0–15	69	24	25	26	25	21	5.2	Good
Sky blue	65		0–15	76	24	43	27	23	11	12.0	Good
Black	21		0–15	51	10	10	10	9	9	11.2	Low
White	92	Single-layer optical brightener	15–30	82	66	221	79	43	32	3.1	Excellent
White	88		0–15	90	67	84	77	60	47	2.2	Excellent
White	85		0–15	89	47	43	48	49	40	2.2	Excellent
White	86	Double-layer elastic perforated simple	0–15	80	47	52	55	49	41	2.5	Excellent
Green	55		30–45	79	39	72	45	30	17	5.9	Very good
Green	51		0–15	77	42	51	43	36	25	3.9	Excellent
Yellow	74		0–15	82	47	48	50	52	38	2.5	Excellent
Yellow	77		0–15	82	44	65	52	38	21	4.7	Excellent
White	91	Double-layer elastic perforated double	0–15	85	53	64	64	49	31	3.5	Excellent
White	93		0–15	75	34	38	37	31	26	3.9	Very good
Yellow	71		15–30	87	61	105	75	49	26	3.6	Excellent
Orange	55		30–45	73	26	27	28	29	21	3.3	Very good
Orange	52		15–30	92	61	167	71	45	30	3.4	Excellent
Green	49		15–30	75	47	64	53	44	22	5.1	Excellent
Green	45		0–15	76	46	63	53	42	26	3.9	Excellent
Red	29		0–15	82	59	163	68	46	32	3.2	Excellent
Red	28		30–45	82	45	48	54	56	41	2.5	Excellent
Red	24		0–15	78	44	58	47	37	26	4.0	Excellent
Maroon	16		0–15	79	42	51	45	37	30	3.2	Excellent
Dark blue	9		0–15	94	81	65	82	117	114	0.9	Excellent
White	89	Double-layer nonelastic perforated	15–30	90	95	84	113	128	107	1.0	Excellent
Sky blue	55.5		0–15	91	67	85	81	78	50	2.6	Excellent
Blue	26		15–30	82	54	99	60	39	22	5.0	Excellent
Blue	35		0–15	89	68	97	76	64	31	3.9	Excellent
Dark blue	11		0–15	96	84	77	95	119	97	1.0	Excellent
Dark blue	15		0–15	92	84	77	95	119	97	1.0	Excellent
Red	19		0–15	72	40	42	43	43	29	3.6	Excellent
Red	16		0–15	93	77	148	91	56	30	3.3	Excellent
Dark gray	24		30–45	77	49	53	56	54	42	2.3	Excellent
Black	7		30–45	73	32	28	35	44	35	2.6	Good

NMSC = nonmelanoma skin cancer; PHAG = photoaging; PHINM = photoimmunosupression; UPF = ultraviolet protection factor; UVA = UVA transmittance; Vit D_3 = previtamin D_3.

The influence of humidity on the different biological factors of fabrics was evaluated by analyzing the effects of water and sweat on five single-layer stretch fabric samples and five double-layer stretch fabric samples. To determine the influence of water, distilled water was used. For sweat, collected sweat (30 mL) from a volunteer wearing a plastic T-shirt fastened at the waist by an elastic band who was asked to run at a fast pace on a treadmill for 30 min was used. Both the collected sweat and distilled water were placed in a bottle and stored overnight at 4°C. The tests were carried out the following morning by the same procedure indicated above. In all cases, 5×5 cm^2 fabric samples (five samples per fabric) were immersed in distilled water or sweat and placed on filter paper to remove excess liquid.

The final biological factor for the single-layer and double-layer fabric types in the cases of dry, wet water and wet sweat fabrics were calculated as the 90% confidence interval according to the normal distribution for the mean of five samples:

$$\text{BIO. FACTOR} = \overline{\text{BIO.FACTOR}} \pm Z_{\propto_2} \bullet \frac{s}{\sqrt{n}} \quad (3)$$

where BIO.FACTOR is the ultraviolet protection for each type of fabric and each type of biological effect; $\overline{\text{BIO.FACTOR}}$, the mean value of the biological effect considered for a sample of n elements; $Z_{\propto_2}$, the normal score for a 90% confidence interval; s, the standard deviation for n elements; and n, the number of elements in the sample.

The effect of color related to different biological protection factors has been analyzed taking into account the differentiation factor of dark color related to clear color. In this way, different color tonalities that could allow to more result variability was simplified by using the level of dark and clear tonalities. Those tonalities were measured by means of a Color meter (Dermalab, Cortex Tech. Copenhagen, Denmark) based on the CIELAB or $L^*a^*b^*$ color space model (from International Commission of Illumination CIE) that enables accurate measurement and comparison of all perceivable colors using three color values. In our case, the L^* data, regarding lightness from black to white on a scale of zero to 100 was used. Values of a^* (from green to red color) and b^* (from blue to yellow) represent chromaticity with no specific numeric limits. Fabric with L^* data lower from 40 corresponded to dark colors, and L^* values over 40–100 were selected as clear colors.

Statistics. Significant differences between the mean protection values corresponding to the different groups resulting from the proposed classification (single-layer, single-layer optical brightener, double-layer elastic perforated simple, double-layer elastic perforated double, and double-layer nonelastic perforated) as well as the fabric humidity test were studied by one-way analysis of variance (ANOVA) followed by the Tukey B test in order to analyze the differences by group. Statistical significance was set at $P < 0.05$. Comparison of mean L^* color dark color values (0–40) with respect to clear L^* values were compared by Student t-test analysis. Pearson correlation test was carried out between the different biological factors studied and cover factor, between the UPF factor and UVA transmittance and between, cover UPV and color lightness.

RESULTS

The results corresponding to the values of the different factors studied, UPF (erythema), Vitamin D3, NMSC, photoimmunesupression, and photoaging are shown in Table 1. Considering the

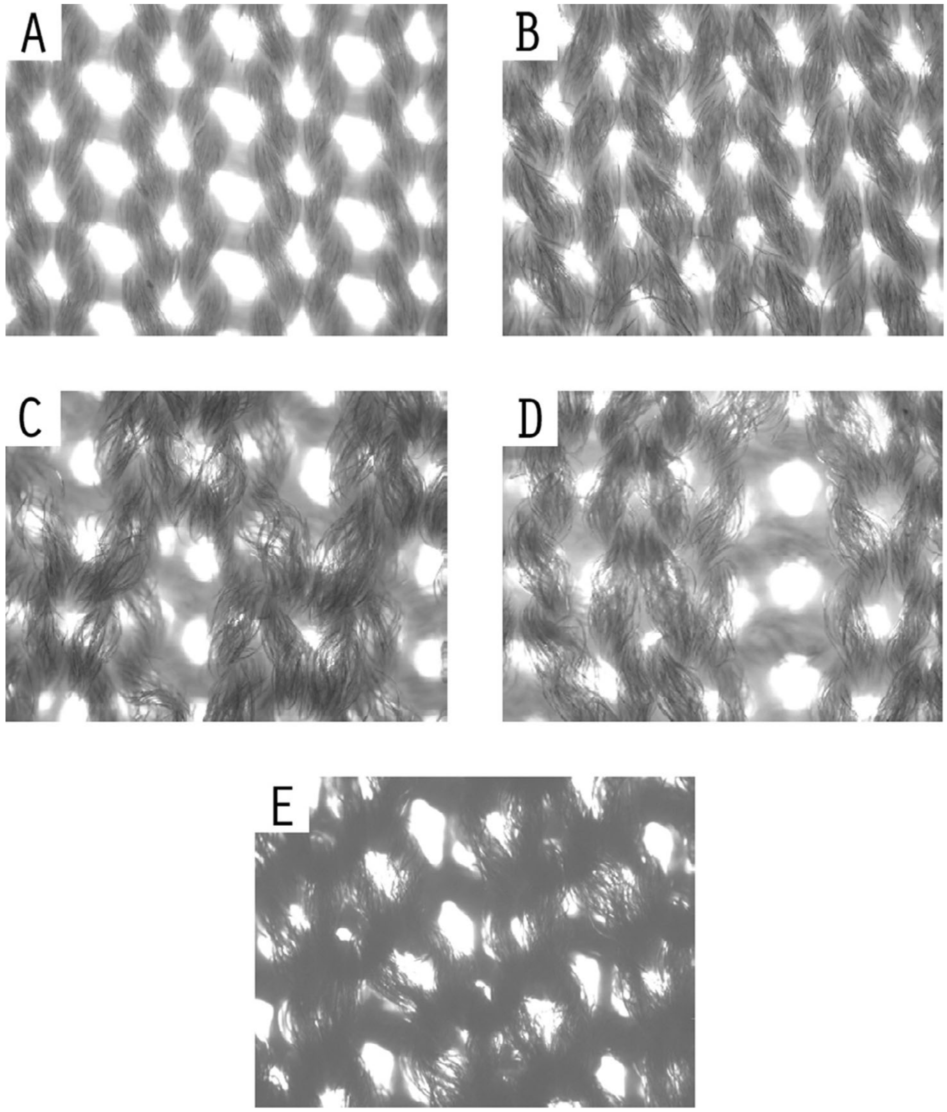

Figure 1. Microscopic image of different 100% polyester technical fabrics analyzed. Magnification ×40. (A) single-layer, (B) single-layer with optical brightener, (C) single-layer elastic, (D) double-layer elastic, (E) double-layer nonelastic.

classification (Biological Factor 40–50+) excellent, (Biological Factor 25–39), very good (Biological Factor 15–24), good (Biological Factor < 15), and low, we find that in the case of UPF, 76% of garments offer excellent protection, 12% very good, 6% good and 6% low. For Vitamin D3, 82% of garments offer excellent protection, 12% very good, 3% good, and 3% low. For the NMSC, 79% of garments offer excellent protection, 15% very good and 6% low. For photoimmunesupression, 65% of the garments offer excellent protection, 26% very good, 3% good and 6% low. For photoaging, 29% of garments offer excellent protection, 44% very good, 18% good and 9% low.

The trend of biological effects that are directly proportional to UVB radiation, such as non-melanoma skin carcinoma and photoimmunesupression, follow a trend similar to that of UPF. More approximate in the case of the non-melanoma skin carcinoma. Biological effects that are inversely proportional to UVB radiation show an inverse trend. Such is the case of the potential production of provitamin D3, which was low in all fabrics due to their low permeability to UVB radiation.

With regard to the transmittance in the UVA range, the results collected in Table 1 indicate that only 21% of the garments analyzed have a transmittance in this range >5%.

From the optical analysis and according to the values in Table 1, we can say that 24% of the garments have cover factor greater than 90%, 32% cover factor between 80–89%, 35% cover factor between 70–79%, 6% between 60–69%, and only 3% less than 60%.

The ANOVA analysis performed for the UPF factor by type of fabric showed significant differences ($P < 0.01$). The subsequent Tukey B test shows that these differences occur between the single-layer type fabrics and the rest of the types (bright single layer and double layer) ($P < 0.01$). Between gloss single-layer fabrics and all the double-layer types no significant differences were found.

From the correlation study between variables, the relationships shown in Fig. 2 were obtained, with Pearson correlation coefficients >0.75 for the cases of UPF f(Cover factor) and NMSC, higher than 0.60 for the cases of photoimmunesupression and UFP f(UVA transmittance) and below for the rest of the cases.

Figure 3 shows the mean values of biological protection factors of fabrics when saturated by water and sweat. The single-layer type saturated with water significantly ($P < 0.05$) increased the value of all the biological factors analyzed, 22.6% vitamin D, 28.5% UPF, 29.7% NMSC, 33.2% photoaging, and 35.5% photoimmunesupression. In the case of sweat, the increases ($P < 0.05$) were 32.7% vitamin D, 30.8% UPF, 33.6% NMSC, 29.7% photoaging, and 34.8% photoimmunesupression. In the double layer, the water produced a decrease of 21% vitamin D, 2.2% UPF, 2% NMSC and an increase of 15.1% photoaging, and 14.5% photoimmunesupression. In the case of sweat, we only have increases of 19.2% vitamin D, 21.3% UPF, 24% NMSC, 13.5% photoaging, and 21.8% photoimmunesupression (see Fig. 3).

In order to analyze the fabric color with respect to biological protection factors, measurements of the lightness level of the fabric associated to color were done by using a color meter that offers L^* values from dark to clear colors (0-black to 100-white) as shown in Table 1. In Fig. 4, the fabric cover as well as the fabric UPF as example of biological protection with respect to the L^* values are shown. The regression lines did not show any significant relationship between color lightness with respect to protection level (regression coefficients of 0.0025 and 0.0258). So, no color effect was observed. The Student t-test between mean L^* values of darker colors (0–40 lightness level) and bright color did not show significant differences ($P = 0.078$).

DISCUSSION

Good weather favors the practice of outdoor sport, but this is when UV radiation levels from the sun's rays are at their highest. Outdoor athletes have an increased risk of diseases linked to chronic UV radiation exposure (24). In this study, we analyzed the barrier properties of technical sportswear fabrics against the sun and its effects. We calculated specific UPF values for the fabrics analyzed according to EN 13758-1 (2001 + A1:2006), equivalent factors referred to others biological effects and also analyzed the influence of sweat and water.

Some studies have reported that approximately one-third of all summer clothing, including sportswear, has a UPF of <15, (11,13), which means that it does not offer enough protection against solar erythema. A garment's UPF rating is influenced by several factors, including the type of fabric (25). Cotton and linen, for example, which typically have a plain-weave pattern, rank low in protective capacity, while most knit garments offer high or very high protection.

Our results show that the percentage of technical fabrics analyzed that offer excellent protection varies depending on the type of effect. In general, the percentage that reaches this level of protection is greater than 75% for all purposes, being slightly less than 65% in the case of photoimmunesupression and low for photoaging with only 29% of garments, the latter case as a result of a action spectrum with more effective wavelengths in higher ranges of the spectrum from 315 nm.

In view of the data obtained from the ANOVA for the UPF based on the type of fabric structure, we conclude that the group of single-layer garments significantly affects the percentages indicated above, with the levels of protection achieved by these garments and for this factor of good and to a greater extent low. Considering the similarity between the action spectra associated with UPF, NMSC and the synthesis of vitamin D3 and the data recorded in Table 1, we can extend this conclusion to these effects. The nonconsideration of single-layer garments modifies the levels of protection achieved by effect as follows: 87% for UPF, 90% for the synthesis of Vitamin D3, 90% for photoimmunesupression, and 30% for photoaging.

Based on the foregoing, we can state that, of the sample of garments analyzed, those with a double-layer or single-layer gloss structure will generally offer excellent protection against erythema, vitamin D3 synthesis, NMSC, and photoimmunesupression. Effective protection against photoaging will require other types of fabric structures or finishing treatments.

Based on the results of our regression analysis, in which the different biological factors are matched with the level of cover factor offered by the different fabrics of the garments that make up our sample census, we can say that cover factor is the controlling factor for the case of UPF, NMSC, and photoimmunesupression. This aspect seems contradictory since sportswear technical fabrics are designed to guarantee high breathability and elasticity (14).

Previous studies have shown that fabrics would need a cover factor of 90%, 95%, 97.5%, and 99.5% to provide a UPF value of 10, 20, 40, and 200, respectively, while others have reported percentages of the 90%, 94%, and 96% for values of 15, 25, and 40. The cover factor factors in our series were lower: 57% for UPF 15, 68% for UPF 25, and 78% for UPF 40, probably because the structure and 100% polyester fabric differs from 100% cotton. In a previous study of summer fabrics by our group, we studied these differences at the microscopic level (13).

Porosity largely depends on type of weave and finish, two important considerations when designing high-performance sportswear. Single-layer fabrics were the most porous, with porosity decreasing with number of layers. The other fabrics had a cover factor of over 70%, and the majority (75%) offered excellent protection against the sun's rays. Adding an optical brightener modifies the texture of a fabric, reducing its porosity (Fig. 1) and altering its optical properties and hence reflectance. By increasing the proportion of light reflected off the surface, optical brighteners would theoretically reduce the amount of incident light falling on the skin.

Design decisions and choice of sportswear for particular sports should be based on prior studies of UV radiation exposure levels. Athletes should not wear garments with a UPF of less than 40 in locations or at times of the year with a UV index of 9–10 in the midday sun. An athlete with unprotected Fitzpatrick type II skin on such a day, without cloud cover, would be exposed to a UV radiation dose over 20 times the minimal erythemal dose (MED). The use of sportswear with a UPF of 40 or higher in the same conditions would reduce the dose received by covered skin to 1 MED at most (9,13).

Exposure to UV radiation is the main risk factor for NMSC (25), which is associated with a very similar action spectrum to that of erythema (26). The fabrics analyzed offered excellent protection against erythema and consequently against NMSC. UV radiation also has a deleterious effect on skin immunity, mostly through DNA damage to Langerhans cells. UVA and high-density radiation in the visible spectrum induce delayed effects such as oxidative stress, which is associated with photoimmunesupression (27). Overall, 94% of the fabrics studied had a UVA transmittance of less than 10%, meaning they offer excellent protection against UVA-induced damage; however, to label a garment according to

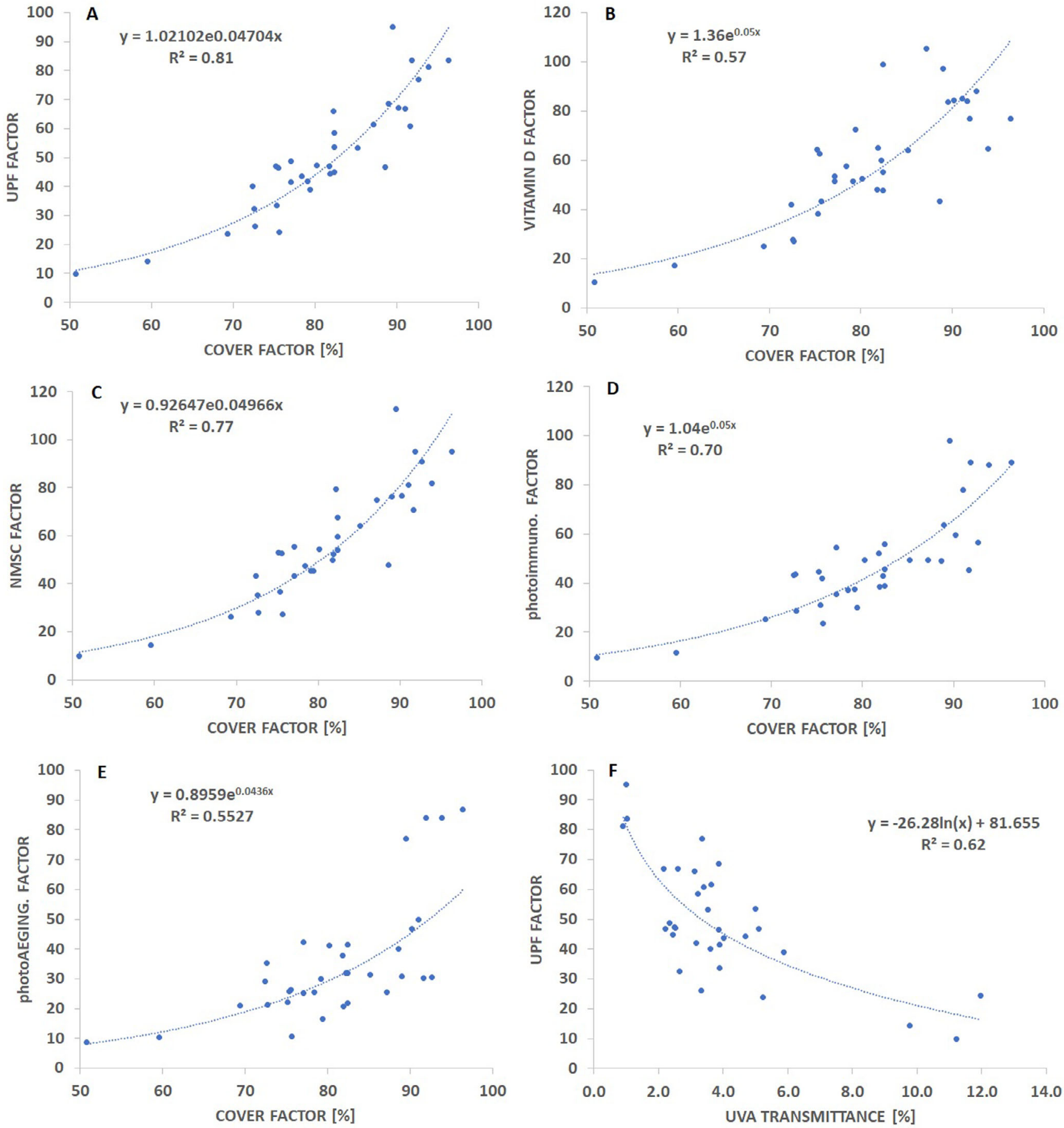

Figure 2. Regression functions showing (A) UPF factor values *versus* cover factor [%], (B) Vitamin D3 factor values *versus* cover factor [%], (C) NMSC factor values *versus* cover factor [%], (D) Photoimmunesupression factor values *versus* cover factor [%], (E) Photoaging factor values *versus* cover factor [%], (F) UPF factor values *versus* UVA transmittance.

the standards of EN 13758–2:2003 + A1:2006, the transmittance corresponding to the UVA band must be <5%, which occurs in 83% of the fabrics studied. As can be seen in Table 1, there is a certain correlation between the UPF values and the transmittance in the UVA range, thus, we can indicate that in general UPF values greater than 40 achieve UVA transmittances of <5% (see Fig. 2). These results warn that the type of technical fabric analyzed not only achieves good UPF values, fundamentally affected by the UVB band, but also achieves good protection values against UVA, radiation with a significant contribution to photocarcinogenesis, photoaging, and other photosensitive disorders. This good behavior against UVA radiation is a parameter of special consideration for athletes with photosensitive dermatoses such as polymorphous light eruption, solar urticaria, chronic actinic dermatitis, porphyria, and photoallergic/phototoxic dermatoses (28).

UV radiation, mostly within the UVB range of the spectrum, also has a role in stimulating the production of provitamin D3.

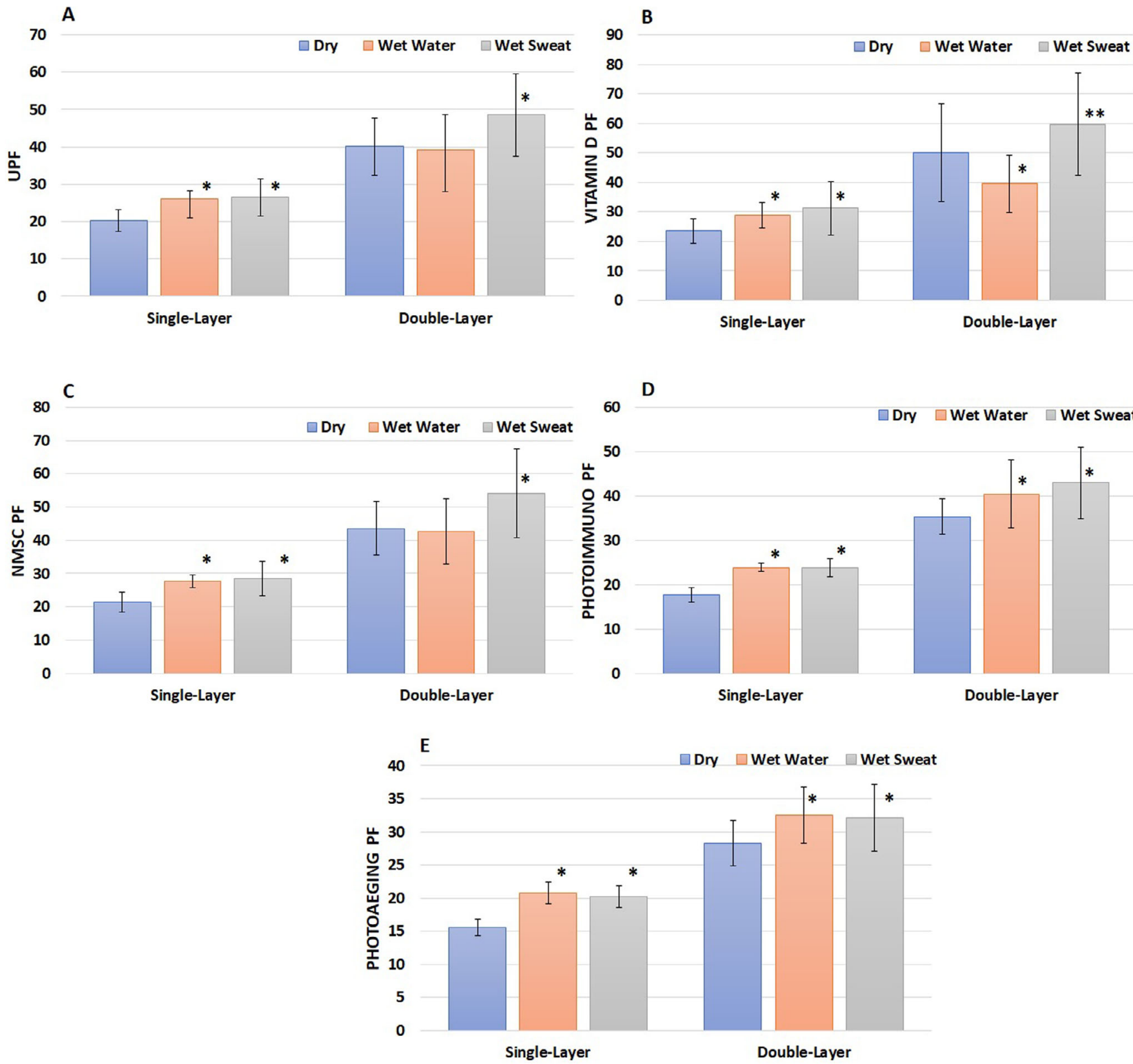

Figure 3. Influence of moisture (distilled water and sweat) on UV protection factors of fabrics. (A) UPF, (B) Vitamin D3, (C) NMSC, (D) Photoimmunesupression, (E) photoaging. The (*) indicates significant differences between moisturizing treatments with respect dry sample after one-way ANOVA.

This is a beneficial effect, which could be reduced by the use of technical fabrics with high levels of protection against UVB radiation. In other words, under normal conditions of sun exposure, the body would not receive a sufficient dose of UVB radiation to effectively stimulate the production of sufficient amounts of vitamin D3. Parisi and Wilson (29), in a study of manikins wearing T-shirts exposed to sunlight for 3 h, reported that covered areas of the body received 0.22 MEDs, which is insufficient to stimulate the production of vitamin D3. Unexposed areas, by contrast, received 15 MEDs (the skin type tested was type II). Nonetheless, it should be noted that sun-protective fabrics would not have a particularly relevant impact on provitamin D3 production, as unexposed parts of the body (*e.g.*, the face, arms, or legs) would receive sufficient doses of sunlight. An MED of 0.25, for example, is considered sufficient to produce healthy levels of provitamin D3 (1000 IU) (30).

Sweat or water can alter the optical and thus sun protection properties of a fabric by changing the scattering of light (32). When a fabric gets wet, the yarn absorbs water and expands, reducing the percentage of free space, particularly in hydrophilic fabrics, such as cotton and linen. Polyester is hydrophobic and, therefore, moisture should not affect its three-dimensional structure, but solar scattering and, consequently, its ability to protect against UV radiation. Our results confirm that this is the case. The immersion in distilled water increased an average of 30% the value of the different biological factors of the fabrics of a single-layer, in the case of double layer the water decreased the biological factors associated with the effects of erythema,

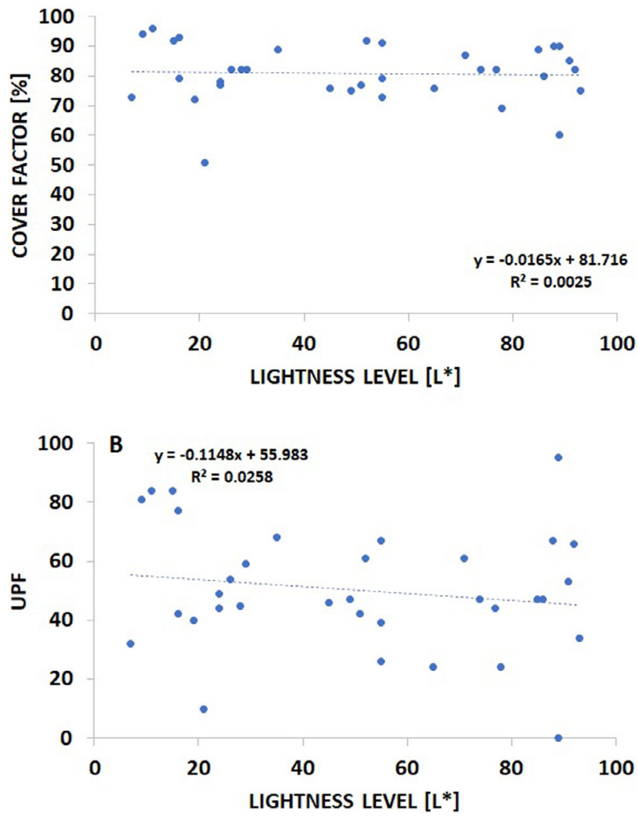

Figure 4. Regression functions showing (A) Cover factor [%] values *versus* lightness [L^*] and (B) UPF values *versus* lightness [L^*].

NMSC, and synthesis of vitamin D3, and an average increase of 15% in factors associated with photoimmunesupression and photoaging. However, immersion in sweat resulted in significantly greater protection in both cases, with an average increase of 32% in single-layer fabrics and 20% in double-layer fabrics. This greater effectiveness of sweat is probably due to the fact that sweat contains substances that absorb UV rays, such as urocanic acid, and other substances, such as cell particles, that could help block some of the radiation.

The fabric color, differentiated by dark and clear color, did not significantly affect the biological protection factors. In the case of fabrics of different materials such as linen or cotton, we have previously described the effect of dark color in the protection factors for different biological effects (11). However, in the case of polyester fabrics, the dyeing of the yarn do not confer more protection capabilities may be due to a different dyeing process in the yarn fabrication. In case of natural fabrics, the dyeing is done or by exhaustion, or saturating the yarns with dye due to affinity or by impregnation of the fiber with a dye solution. Thus, the dye is joined to yarn as an external compound with a consequent decrease in space between yarns as well as their absorption properties. In case of polyester yarn dyeing, named "dope dyed" yarn, the dyes are added directly to the polymer melt before the extrusion process, the dyes are uniformly dispersed in the polymer and after extrusion are permanently integrated into the structure of the resulting yarn. So, the space between yarns that allows the cover effect of the fabric is not affected, and we have found no color effect on the biological protection factors.

CONCLUSIONS

The sample analyzed of 100% polyester two-layer and gloss single-layer technical sports fabrics offer excellent protection against erythema (UPF), NMSC, and immunosuppression in more than 70% of the cases studied. The remaining 30% offers very good protection. The effectiveness of protection against photoaging of these garments is significantly reduced, reaching an excellent rating of only 33% of the garments and 47% very good. On the contrary, they hinder the synthesis of Vitamin D, increasing the required sun exposure times from 27 times onward. UVA transmittance is less than 5% in 93% of the garments.

The protection offered by monolayer type fabrics for the different biological effects is mostly low.

The cover factor acts as a controlling variable in the values of the UPF factor and the NMSC factor, where the trends are adjusted to an exponential function with correlation coefficients of 0.81 and 0.77, respectively, and being very influential for the rest of the biological effects.

In single-layer garments, both sweat and water affect positively and to a similar extent the value of all the factors studied. In double-layer garments, sweat increases the value of all factors. Water has little significant influence on the UPF and NMSC factors, positive on the photoimmunity and photoaging factors, and negative on the Vitamin D factor.

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