processes

MDPI

Article

Evaluation of the Effectiveness of Protective Lipsticks with Different Sun Protection Factor Values Against UVA and Infrared Radiation

Monika Zemła-Krawczyk and Beata Sarecka-Hujar *

Department of Basic Biomedical Science, Faculty of Pharmaceutical Sciences in Sosnowiec, Medical University of Silesia in Katowice, 8b Jedności Str., 41-200 Sosnowiec, Poland; monika0719@gmail.com
* Correspondence: bsarecka-hujar@sum.edu.pl; Tel.: +48-32-2699830

Abstract

Sunlight contains a wide spectrum of radiation from ultraviolet (UV) through visible light to infrared (IR). UV radiation plays a crucial role in skin damage, photoaging, and carcinogenesis, necessitating effective photoprotection strategies. The study evaluated the efficacy of protective lipsticks with different sun protection factor (SPF) values (10, 15, and 30) against UVA and infrared (IR) radiation. In this study, the directional-hemispherical reflectance (DHR) was measured across various spectral bands (335–380 nm, 400–540 nm, 700–1100 nm, and 1000–1700 nm) with SOC 410 Reflectometer (San Diego, CA, USA). Since the device used in this study did not cover the UVB range (290–320 nm), this study does not provide a direct assessment of SPF in its conventional sense. The measurements were taken at four time points up to 120 min after lipstick application. Results indicated that lipsticks with higher SPF values significantly altered skin reflectance in UVA and IR ranges, with SPF30 showing the lowest reflectance in the UVA range (335–380 nm), suggesting greater absorption of UVA radiation by the product and significantly higher reflectance in IR ranges compared to lower SPF lipsticks. Reflectance values generally increased over time post-application for key spectral bands. These findings demonstrate that SPF lipsticks provide variable attenuation of UVA and IR radiation, highlighting their role in comprehensive lip photoprotection. The data support the importance of SPF selection for optimized protection, especially against penetrating UVA and IR components of sunlight.

Keywords: hemispheric directional reflectance; SPF values; cosmetics products; sun protection

check for updates

Academic Editor: José A. Peres

Received: 2 August 2025
Revised: 1 September 2025
Accepted: 4 September 2025
Published: 8 September 2025

Citation: Zemła-Krawczyk, M.; Sarecka-Hujar, B. Evaluation of the Effectiveness of Protective Lipsticks with Different Sun Protection Factor Values Against UVA and Infrared Radiation. *Processes* **2025**, *13*, 2864. https://doi.org/10.3390/pr13092864

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Exposure to ultraviolet (UV) radiation remains a major risk factor for skin damage, photoaging, and skin cancers [1]. Sunlight that reaches the Earth's surface forms a continuous spectrum of electromagnetic radiation, spanning wavelengths from about 290 nm to roughly 3000 or even 4000 nm. Sunscreen products, which are traditionally formulated as creams or sprays, show an essential role in photoprotection against UV light [2,3]. The effectiveness of SPF filters in cosmetics, including lipsticks, depends both on their ability to absorb or reflect harmful UV radiation and on factors such as photostability and the formation of a coherent film [4]. Sunscreens can include various types of filters (physical (mineral) or chemical (organic)) along with non-filtering active ingredients that enhance their photoprotective effectiveness. Recent research suggests the necessity of balanced photoprotection from both UVB and UVA radiation, as both contribute to skin damage and

cancer risk [5]. While UVB primarily causes sunburn and DNA damage in skin cells, UVA penetrates deeper, contributing to photoaging and potentially leading to skin cancer [6]. To determine the actual sun protection of cosmetics containing a sun protection factor (SPF), traditional methods are used that measure the minimum erythemal dose (MED) or are based on SPF measurements in vivo, compliant with standards such as International Organization for Standardization (ISO) 24444 [7] or COLIPA guidelines [8]. Nowadays, these protocols may be supplemented with optical measurement techniques that quantify, among other things, the hemispherical directional reflectance value, indicating how much incident UV radiation or visible light is reflected from the skin surface after product application [9].

Directional-hemispherical reflectance (DHR) measurements provide a nuanced, spectrally resolved assessment of photoprotective performance. This technique has recently been used to analyze the photoprotective properties of sesame oil or different types of creams, also those containing SPF [9,10].

Compared to other areas of the body, e.g., back, the skin on the lips shows distinct characteristics because it is much thinner, composed of only a few cell layers, and is covered by a very delicate orthokeratotic *stratum corneum* with minimal melanin pigment [11]. This unique anatomy makes the lips especially vulnerable to chemical, physical, and microbiological damage [12]. There are also significant differences in the structure of the skin between women and men, resulting mainly from hormonal and biological factors [13].

When it comes to daily sun protection, specific anatomical areas like the lips can often be overlooked, despite their increased sensitivity to UV damage. However, there is an increasing number of sunscreen lipsticks on the market. Given the anatomical uniqueness of the lips and the diverse physicochemical makeup of lipstick formulations, there is a clear need for comprehensive studies evaluating the UV-protective performance of these products, using robust, quantitative methods beyond classical SPF testing.

This study aimed to evaluate the photoprotective properties of lipsticks with different SPF using the DHR method but beyond the classic SPF definition, i.e., in terms of UVA, visible, and infrared radiation. This approach may provide valuable information on both the potential and limitations of these cosmetics as effective photoprotective agents, especially when skin is exposed not only to sunlight but also to artificial infrared radiation.

2. Materials and Methods

2.1. Tested Products

The protective lipsticks were selected for this study after a thorough analysis of the Polish cosmetics market to identify products with different SPFs within one brand, to avoid measurement errors related to differences in the cosmetics manufacturing process between companies. All lipsticks featured similar shades and gloss levels to minimize confounding effects from color or vehicle-related reflectance alterations. Prior to each application, the skin area was measured to establish a baseline reflectance, facilitating analysis of relative changes following product exposure.

Ultimately, the study was conducted on lipsticks with SPF values of 10, 15, and 30. Analysis of the composition of model protective lipsticks showed that as the SPF value increases, the number of photoprotective substances used in the formula increases. A product with SPF10 contains one such substance (Ethylhexyl Methoxycinnamate), a lipstick with SPF15 contains two ingredients with photoprotective properties (Homosalate, Ethylhexyl Salicylate), and the SPF30 lipstick contains four ingredients of this kind (Homosalate, Ethylhexyl Methoxycinnamate, Benzophenone-3 (Oxybenzone), and Ethylhexyl Salicylate). The mentioned-above substances, i.e., Ethylhexyl Methoxycinnamate, Homosalate, Ethylhexyl Salicylate, and Benzophenone-3 (Oxybenzone) are allowed in cosmetics at maximum thresholds of 10%, 7.34%, 5%, and 6%, respectively [14]. Each lipstick contained

also CI 77891 (titanium oxide, in nano-form in the SPF30 lipstick) which was last on the ingredient list and served as a colorant.

Filter concentrations are not precisely available for the tested lipsticks and can only be estimated based on typical manufacturer information or INCI order.

2.2. Study Group

The study was conducted on the inner skin of the forearms of 23 women (22–63 years of age, with a mean age of 30.22 ± 12.79 years) with Fitzpatrick skin type II. The study group consisted only of women to minimize differences in measurement due to the differing structure of men's skin. The inner forearm was chosen as the measurement site due to its flat surface and accessibility. These parameters are important for the consistent application and performance of the reflectance measurement itself using the SOC 410 reflectometer. The anatomical and physiological complexity of the mouth, including its size and sensitivity, posed significant methodological challenges for standardized, repeatable measurement using currently available devices.

The measurements were performed in the Department of Basic Biomedical Sciences, Medical University of Silesia in Katowice (Poland). The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee of the Medical University of Silesia (No. PCN/CBN/0052/KB1/62/22). Participation in the study was anonymous and voluntary; all volunteers provided informed consent.

2.3. Application of the Tested Lipsticks

On the forearm of each participant, three 3 cm × 3 cm squares were marked. Skin tags and visible blood vessels were avoided when determining the application area. A total of 0.021 g of each test product was weighed and then, using a disposable wooden spatula, the squares were thoroughly covered with a thin layer of the product (Figure 1). The analyzed lipsticks were applied by an experienced cosmetologist (M.Z.-K.). After application, all analyzed lipsticks do not alter lip color or shine, appearing mostly clear with a natural, non-glossy finish.

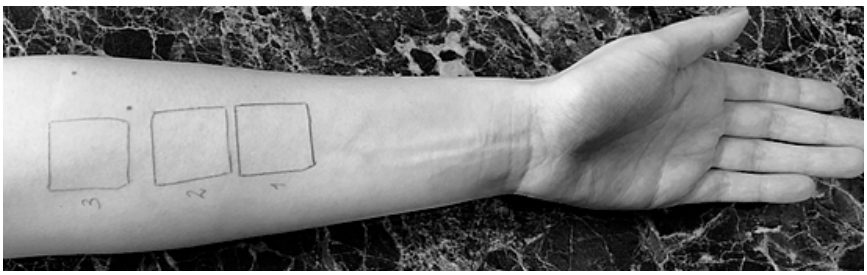


Figure 1. Photograph of the forearm illustrating the placement of measurement fields in this study. Skin tags and visible blood vessels were avoided when determining the application area. Lipsticks SPF10, SPF15, and SPF30 were applied to area 1, area 2, and area 3, respectively.

2.4. Analysis of Directional-Hemispherical Reflectance

The DHR was measured with the SOC 410 Reflectometer (Surface Optics Corporation, San Diego, CA, USA), which allows for the assessment of reflectance from ultraviolet through visible light to near-infrared in seven spectral ranges: 335–380 nm, 400–540 nm, 480–600 nm, 590–720 nm, 700–1100 nm, 1000–1700 nm, and 1700–2500 nm in a 20°/H geometry (directional illumination at 20° to surface normal with hemispheric collection). This wide spectral range supplements the deficiency in the literature regarding full-spectrum protection. The device shows results for total, diffuse, and specular reflectance. However, in the present study, only total hemispherical reflectance (THR) was analyzed.

Before each test, the instrument was calibrated using special calibration coupons provided by the manufacturer. First, the reflectance of clean skin, without cosmetics (control, 0 min), was measured. Then, protective lipsticks were applied in the order described above. DHR measurements were taken at three time points: 20 min, 60 min, and 120 min after applying (time 0) the protective lipstick to the forearm skin. The choice of the moment of the first measurement is justified by the fact that cosmetic manufacturers recommend applying cosmetics with an SPF filter 20 min before sun exposure, while the last measurement was taken 120 min after application, as cosmetic manufacturers indicate the need to apply another layer of the SPF formula after this time.

Three measurements were taken at each time point; thus, 69 measurements were taken for each lipstick in total.

2.5. Statistical Analyses

Statistical analyses of the obtained data were performed using Statistica 13 (StatSoft, Tulsa, OK, USA) and Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA). Data were presented as mean (M) ± standard deviation (SD) values. Considering the number of DHR measurements for each lipstick at each time point, it can be assumed that the variable follows the normal distribution, and due to the central limit theorem, it can be thought that the distribution of these data converges to a normal distribution. Time-dependent continuous variables (reflectance measurements at 20 min, 60 min, and 120 min) were analyzed using repeated-measures ANOVA. If a statistical relationship was found between three measurements, a post hoc Bonferroni test was used to compare pairs of measurements (0 min vs. 20 min, 0 min vs. 60 min, 0 min vs. 120 min, 20 min vs. 60 min, 20 min vs. 120 min, 60 min vs. 120 min). This conservative correction method reduces the number of false positive results while maintaining adequate sensitivity, given the data's structure.

Student's *t*-test was used to compare variables between two groups, while ANOVA tests were used for comparing variables between more than two groups. If the result of this test was significant, post hoc analyses using the Bonferroni test were performed to assess differences between individual pairs of preparations, i.e., SPF10 vs. SPF15, SPF10 vs. SPF30, and SPF15 vs. SPF30. For comparisons with a significant *p*-value, partial eta squared (η) was assessed to estimate the effect size, which was rated as low, medium, or high for values of 0.01, 0.06, and 0.14, respectively.

3. Results

3.1. Changes in the Reflectance of the Skin with the Tested Cosmetics Applied over Time

3.1.1. Lipstick with SPF10

After applying the protective lipsticks, reflectance measurements were taken after 20 min, 60 min, and 120 min. In the case of SPF10 lipstick, mean reflectance differed significantly between subsequent time points for the ranges of 335–380 nm, 400–540 nm, 700–1100 nm, and 1000–1700 nm (Table 1). For these spectral ranges, the reflectance of the clean skin (control) was comparable to the reflectance measured at 20 min, but in the next time points, reflectance increased significantly. The values of reflectance in the remaining spectral bands, specifically 480–600 nm, 590–720 nm, and 1700–2500 nm, did not change over time (Table 1).

Table 1. Mean reflectance values of the clean skin and the skin with applied SPF10 lipstick over time.

Spectral Bands [nm]	THR [a.u.], M ± SD over Time				*p*	*η*
	Control (Clean Skin, 0 min)	20 min	60 min	120 min		
335–380	0.203 ± 0.065	0.196 ± 0.069	0.208 ± 0.084	0.219 ± 0.084	**0.021** [1]	**0.046**
400–540	0.400 ± 0.031	0.397 ± 0.033	0.413 ± 0.035	0.414 ± 0.038	**<0.001** [2]	**0.195**
480–600	0.453 ± 0.190	0.439 ± 0.176	0.409 ± 0.116	0.404 ± 0.112	0.111	-
590–720	0.629 ± 0.176	0.615 ± 0.158	0.580 ± 0.096	0.583 ± 0.099	0.051	-
700–1100	0.534 ± 0.068	0.525 ± 0.070	0.551 ± 0.057	0.558 ± 0.059	**<0.001** [3]	**0.095**
1000–1700	0.292 ± 0.016	0.284 ± 0.017	0.295 ± 0.024	0.296 ± 0.025	**<0.001** [4]	**0.159**
1700–2500	0.096 ± 0.062	0.097 ± 0.063	0.086 ± 0.037	0.083 ± 0.037	0.114	-

THR—total hemispherical reflectance; M—mean; SD—standard deviation; [1] 20 min vs. 120 min $p = 0.017$; [2] control vs. 60 min $p < 0.001$; control vs. 120 min $p < 0.001$; 20 min vs. 60 min $p < 0.001$; 20 min vs. 120 min $p < 0.001$; [3] control vs. 120 min $p = 0.010$; 20 min vs. 60 min $p = 0.011$; 20 min vs. 120 min $p < 0.001$; [4] control vs. 120 min $p = 0.009$; 20 min vs. 60 min $p < 0.001$; 20 min vs. 120 min $p < 0.001$. Statistical differences are in bold. η—partial eta squared.

3.1.2. Lipstick with SPF15

For the SPF15 lipstick, the mean reflectance of the skin did not differ significantly over time for the range of UVA light (i.e., 335–380 nm). However, we found differences in reflectance values for 400–540 nm, 700–1100 nm, and 1000–1700 nm ranges (Table 2). Again, the reflectance of the clean skin (control) was comparable to the reflectance measured at 20 min, but in the next time points, reflectance increased significantly.

Table 2. Mean reflectance values of the clean skin and the skin with applied SPF15 lipstick over time.

Spectral Bands [nm]	THR [a.u.], M ± SD over Time				*p*	*η*
	Control (Clean Skin, 0 min)	20 min	60 min	120 min		
335–380	0.203 ± 0.065	0.190 ± 0.060	0.204 ± 0.085	0.207 ± 0.078	0.113	**-**
400–540	0.399 ± 0.031	0.402 ± 0.033	0.421 ± 0.038	0.416 ± 0.043	**<0.001** [1]	**0.239**
480–600	0.453 ± 0.190	0.452 ± 0.184	0.424 ± 0.118	0.411 ± 0.109	0.163	-
590–720	0.629 ± 0.176	0.620 ± 0.162	0.592 ± 0.108	0.590 ± 0.105	0.158	-
700–1100	0.534 ± 0.068	0.525 ± 0.076	0.559 ± 0.048	0.563 ± 0.049	**<0.001** [2]	**0.134**
1000–1700	0.292 ± 0.016	0.289 ± 0.017	0.299 ± 0.024	0.300 ± 0.026	**<0.001** [3]	**0.145**
1700–2500	0.096 ± 0.062	0.101 ± 0.064	0.088 ± 0.037	0.084 ± 0.037	0.095	-

THR—total hemispherical reflectance; M—mean; SD—standard deviation; [1] control vs. 60 min $p < 0.001$; control vs. 120 min $p < 0.001$; 20 min vs. 60 min $p < 0.001$; 20 min vs. 120 min $p < 0.001$; [2] control vs. 60 min $p = 0.009$; control vs. 120 min $p = 0.002$; 20 min vs. 60 min $p < 0.001$; 20 min vs. 120 min $p < 0.001$; [3] control vs. 60 min $p = 0.012$; control vs. 120 min $p = 0.005$; 20 min vs. 60 min $p < 0.001$; 20 min vs. 120 min $p < 0.001$. Statistical differences are in bold. η—partial eta squared.

3.1.3. Lipstick with SPF 30

In the 335–380 nm range, we observed a decrease in reflectance value after applying the SPF30 lipstick compared to clean skin. In the 400–540 nm, 700–1100 nm, and 1000–1700 nm bands, the clean skin and skin after 20 min application of lipstick showed similar reflectance, and in the subsequent time points, reflectance significantly increased (Table 3).

Table 3. Mean reflectance values of the clean skin and the skin with applied SPF30 lipstick over time.

Spectral Bands [nm]	THR [a.u.], M ± SD over Time				*p*	*η*
	Control (Clean Skin, 0 min)	20 min	60 min	120 min		
335–380	0.203 ± 0.065	0.067 ± 0.025	0.089 ± 0.035	0.089 ± 0.047	**<0.001** [1]	**0.719**
400–540	0.399 ± 0.031	0.397 ± 0.033	0.413 ± 0.040	0.414 ± 0.042	**<0.001** [2]	**0.182**
480–600	0.453 ± 0.190	0.444 ± 0.176	0.417 ± 0.114	0.411 ± 0.095	0.112	-
590–720	0.629 ± 0.176	0.619 ± 0.160	0.586 ± 0.106	0.589 ± 0.089	0.053	-
700–1100	0.534 ± 0.068	0.534 ± 0.072	0.560 ± 0.052	0.568 ± 0.056	**<0.001** [3]	**0.110**
1000–1700	0.292 ± 0.016	0.293 ± 0.017	0.303 ± 0.025	0.305 ± 0.027	**<0.001** [4]	**0.172**
1700–2500	0.096 ± 0.062	0.098 ± 0.065	0.087 ± 0.038	0.083 ± 0.037	0.156	-

THR—total hemispherical reflectance; M—mean; SD—standard deviation; [1] control vs. 20 min $p < 0.001$; control vs. 60 min $p < 0.001$; control vs. 120 min $p < 0.001$; 20 min vs. 60 min $p = 0.010$; 20 min vs. 120 min $p = 0.009$; [2] control vs. 60 min $p < 0.001$; control vs. 120 min $p < 0.001$; 20 min vs. 60 min $p < 0.001$; 20 min vs. 120 min $p < 0.001$; [3] control vs. 60 min $p = 0.035$; control vs. 120 min $p = 0.002$; 20 min vs. 60 min $p = 0.007$; 20 min vs. 120 min $p < 0.001$; [4] control vs. 60 min $p = 0.002$; control vs. 120 min $p < 0.001$; 20 min vs. 60 min $p < 0.001$; 20 min vs. 120 min $p < 0.001$. Statistical differences are in bold. *η*—partial eta squared.

3.2. Comparison of Skin Reflectance Depending on the SPF Value of the Tested Lipstick at Each Time Point

In the spectral range of 335–380 nm, mean skin reflectance differed significantly between different SPFs 20 min after application ($p < 0.001$). Post hoc analysis revealed a significant difference between SPF10 and SPF30 ($p < 0.001$) and between SPF15 and SPF30 ($p < 0.001$) (Figure 2). The most UVA radiation was reflected by the SPF10 lipstick—19.6%, meaning almost 80% was absorbed by the skin. The skin with the SPF30 lipstick reflected the least radiation in this spectral range—6.7% compared to the reflectance of the skin with other SPF lipsticks. In turn, for the IR wavelength range of 1000–1700 nm, skin with SPF30 lipstick had significantly higher reflectance compared to SPF10 ($p = 0.006$) (Figure 2). No such significance was observed for the remaining spectral ranges 20 min after application.

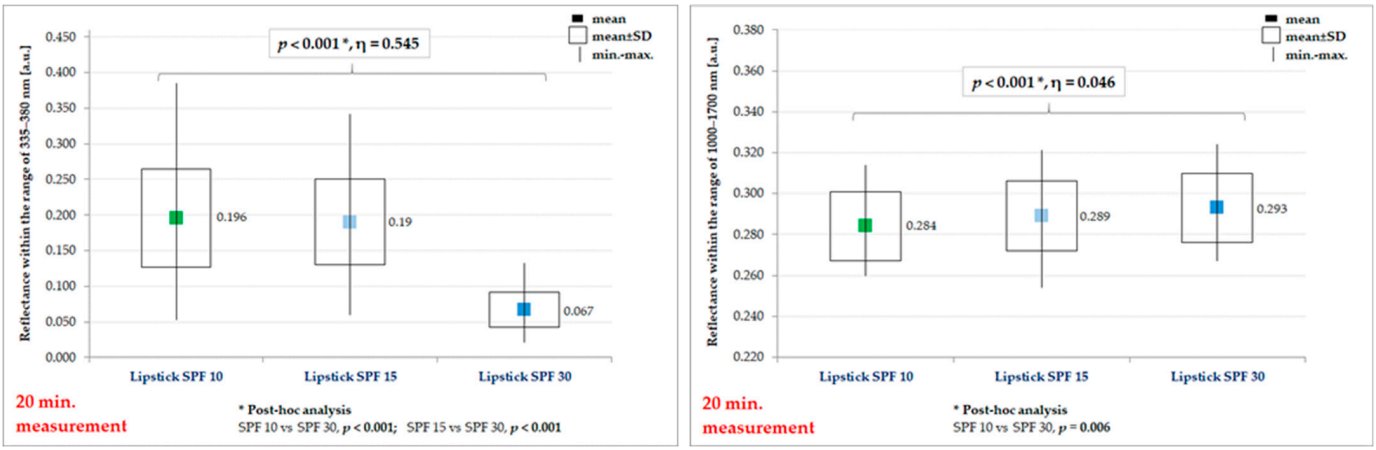


Figure 2. Comparison of mean reflectance values (with SD and min.–max.) of the skin depending on SPF value 20 min after application. SD—standard deviation; SPF—sun protection factor; *η*—partial eta squared. Significant differences are in bold.

At 60 min and 120 min, after applying the lipsticks, a significant difference in skin reflectance was observed depending on SPF, only for the UVA range (335–380 nm), as shown in Figure 3. The amount of light reflected was approximately 21% and 22% for SPF 10 at 60 min and 120 min time points, respectively. For SPF15 and SPF 30, the amount of UV radiation reflected from the skin was similar, regardless of the time.

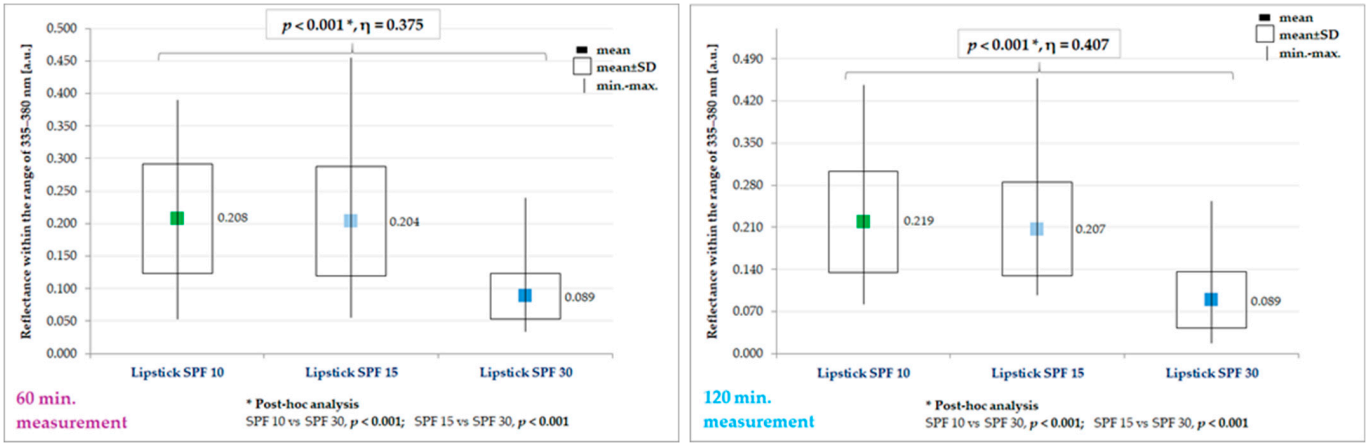


Figure 3. Comparison of mean reflectance values (with SD and min.–max.) of the skin depending on SPF value 60 and 120 min after application. SD—standard deviation; SPF—sun protection factor; η—partial eta squared. Significant differences are in bold.

4. Discussion

In the study, directional-hemispherical reflectance measurements were conducted, which allowed us to assess the radiation protection properties of three protective lipsticks available on the Polish market (SPF10, SPF15, and SPF30) manufactured by one manufacturer. The study analyzed products containing chemical filters, which penetrate the skin and absorb harmful radiation, converting it into thermal energy. Therefore, the reflectance value of skin treated with a cosmetic containing a chemical SPF filter is lower than that of unprotected skin, due to greater absorption of radiation than reflection. In the case of physical filters, skin treated with a cosmetic containing SPF will exhibit higher reflectance than unprotected skin (without a cosmetic).

The decrease in average reflectance of the skin with the protective lipstick 20 min after application, compared to clean skin, indicates that the product began to fulfill its photoprotective function by absorbing radiation. Analysis of the composition of the lipsticks used in the study indicates a higher content of organic filters compared to mineral filters (titanium dioxide was at the end of the INCI list), which explains the greater absorption of energy from radiation compared to its reflection. Although the SPF value on cosmetic packaging, including those of protective lipsticks, refers to UVB radiation (290–320 nm), the present results indicate that the cosmetic also protects skin within the UVA range (320–400 nm). Manufacturers recommend applying cosmetics 20 min before sun exposure and reapplying every two hours. The study confirms this principle, as the average reflectance value decreased over time, thus reducing radiation absorption, making the skin more vulnerable to the negative effects of UV radiation. A comparison of three lipsticks with different SPF values showed that the SPF30 lipstick had the greatest ability to absorb radiation in the 335–380 nm wavelength range 20 min after application, compared to SPF15 and SPF10 lipsticks. The study revealed a similar relationship after 60 and 120 min of application. A significant difference was also observed between the three lipsticks tested in the 1000–1700 nm wavelength range after 20 min of application. The differences in average reflectance were significant for the SPF10 vs. SPF30 comparison and between the SPF15 and SPF30 lipsticks. There was no statistical significance between SPF10 and SPF15 lipsticks. Overall, the results of partial eta demonstrated that protective lipsticks with SPF30 may provide measurably better protection, particularly against UVA and some infrared wavelengths, compared to SPF10 or SPF15.

Human skin is exposed to solar radiation throughout life, even indoors, because some bands of radiation can penetrate, for example, through glass. Nowadays, more and more

people protect their bodies with photoprotective agents. This applies in particular to protection against UVB and UVA radiation, which contributes to the formation of free radicals that accelerate the aging process. Although UVB and UVA radiation account for only about 7% of the solar radiation [15], it is this radiation that has been most thoroughly studied and understood to date. Exposure to UVB causes burning and erythema, while UVA rays contribute to skin aging and carcinogenesis [16]. Infrared radiation, like UV, can lead to skin damage by disrupting the homeostasis of the extracellular matrix and degrading connective tissue. IRA radiation penetrates deeper into the skin than UV, reaching the dermis where fibroblasts reside, thus contributing significantly to photoaging through reactive oxygen species (ROS)- and matrix metalloproteinase 1 (MMP-1)-dependent collagen degradation [17]. Unlike UVB/UVA, IRA affects a broader spectrum of genes, including those regulating calcium signaling and antiapoptotic pathways, underscoring its unique impact and clinical relevance in dermatology. Calles et al. [18] demonstrated that approximately 600 genes respond to infrared radiation in human skin fibroblasts. Photoprotection of human skin in this radiation range is primarily based on the use of topical antioxidants [19]. The problem is the lack of standardized in vitro or in vivo tests to confirm the photoprotective properties of patented antioxidants. Also, visible light was demonstrated to have an impact on human skin, and it can contribute to skin aging and wrinkle formation, primarily through oxidative stress and collagen breakdown pathways [20,21]. It has been proven that it influences the development of hyperpigmentation, and the mechanism of pigmentation caused by blue light differs from that caused by UVB radiation [22]. Photoprotection in the 400–770 nm wavelength range is based on light scattering or reflection. Such preparations, which contain inorganic pigments (such as iron oxide, titanium dioxide, or zinc oxide), are insoluble in water and leave a white or colored layer on the skin, which is unsatisfactory for most consumers [23].

The photostability of SPF filters is essential to maintain UV protection and prevent harmful photo-oxidants. Previously, it was demonstrated that benzophenone-3 (BP–3) has a relatively good photostability after 4 h irradiation, also in a complex with other sunscreens [24]. In a study by Gonzalez et al. [25], the photostability of commercially available sunscreens was analyzed. In three of the six sunscreens, the authors observed degradation of the butyl methoxydibenzoylmethane (BMDBM) molecule after 90 min of exposure to UV radiation. In turn, five of the analyzed sunscreens were stable in the UVB region. The authors suggested the need to include information about photostability on sunscreen packaging [25].

Our findings represent a model of photoprotection on Fitzpatrick type II skin, and future research should include protocols with lip-specific instrumentation or clinical trials directly involving the lips to validate product effectiveness further. The advantage of the methodology used in this work is the wide spectral range that can be analyzed, including three infrared radiation ranges: 700–1100 nm, 1000–1700 nm, and 1700–2500 nm. Currently, there is no standardized method to directly measure IRA photoprotection in vivo; thus, reflectance analysis provides valuable but preliminary insights. There is a deep need to integrate molecular biomarkers and clinical parameters to establish the efficacy of lipoprotective products against IRA-induced skin damage and aging. However, a growing number of cosmetic manufacturers offer products that protect against infrared radiation. In a study by Wilczyński et al. [26], commercially available cosmetic products (selected UV filters, care creams, and preparations containing fumed silica) were analyzed using a reflectometer and demonstrated that they do not protect the skin against infrared radiation. Infrared radiation is strongly absorbed by the water contained in human tissues, leading to heating and negative clinical effects, including the activation of metalloproteinases, which consequently accelerates the formation of new wrinkles. Other studies of cosmetic

preparations using directional reflectance included oils from chokeberry, fig, pomegranate, and perilla, for which a significant increase in skin reflectance in the 1700–2500 nm range was observed after oil penetration, which may indicate their protective potential against infrared radiation [27].

The present study is the first to present data on the potential UVA and IR protection offered by lip balms already on the market. Previous data only analyzed UVB protection using standard methods. The study by Gfeller et al. [28] presented SPF values for five new lip balm formulations that were tested according to the final monograph regulations of the US Food and Drug Administration (FDA) or the international standard ISO 24444 and found that, despite demonstrating sun protection, the tested formulations did not achieve the target SPF.

Our study has certain limitations, including the small number of participants to analyze data by age. Additionally, the device used in the analysis does not allow for the assessment of UVB reflectance, only a part of UVA. Also, we are aware that the structural properties of lip skin, such as a reduced thickness of *stratum corneum*, may influence the efficacy of lipsticks compared to the forearm skin. The forearm was used as a surrogate sample in this study, and these results should be interpreted as an approximation rather than a direct measurement of lip efficacy. Lip-specific testing protocols and instruments are warranted in future studies to verify these results under real-world conditions. In addition, reflectance values may be affected by slight variations in the protective lipstick layer thickness resulting from manual sample application. To overcome this problem, future studies using objective assessment of layer thickness (e.g., profilometry, cross-sectional imaging) may further improve the accuracy of this assessment. However, despite these shortcomings, the work is innovative, as it allows fora quick and simple way to test the properties of cosmetics within a wide spectral range of radiation.

5. Conclusions

In conclusion, protective lipsticks with SPF10, SPF15, and SPF30 demonstrate a statistically significant increase in reflectance over time after application in the following ranges: 335–380 nm, 400–540 nm, 700–1100 nm, and 1000–1700 nm. The mean value of total reflectance differs significantly between the three lipsticks tested, depending on SPF, in the wavelength ranges of 335–380 nm and 1000–1700 nm after 20 min of application. The mean reflectance for the lipstick with SPF30 is significantly lower compared to the mean reflectance for the lipsticks with SPF10 and SPF15. Similar relationships were demonstrated after 60 min and 120 min of application for the wavelength range of 335–380 nm.

The measurements reported in the study are not equivalent to SPF determination by standard in vivo or in vitro protocols (such as ISO 24444 or COLIPA guidelines), which emphasize UVB-induced erythema. Additionally, hybrid diffuse reflectance spectroscopy (HDRS) has recently been established as a new, noninvasive method (ISO 23698) combining in vivo and in vitro measurements to assess sun protection efficacy (SPF, UVA-PF, critical length) [29]. Our work goes further by examining the additional yet often overlooked photoprotective properties of lipsticks labeled with SPF against wavelengths longer than standard UVB, i.e., UVA and IR. This alternative assessment addresses a documented gap in both research and clinical practice, where lip protection against the full sunlight spectrum is of growing concern.

Author Contributions: Conceptualization, M.Z.-K. and B.S.-H.; methodology, M.Z.-K. and B.S.-H.; software, B.S.-H.; formal analysis, B.S.-H.; investigation, M.Z.-K. and B.S.-H.; resources, M.Z.-K. and B.S.-H.; data curation, M.Z.-K. and B.S.-H.; writing—original draft preparation, M.Z.-K. and B.S.-H.; writing—review and editing, M.Z.-K. and B.S.-H.; visualization, B.S.-H.; supervision, B.S.-H.; project administration, B.S.-H.; funding acquisition, B.S.-H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Medical University of Silesia in Katowice, Poland within the project BNW-1-107/N/4/I.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee of the Medical University of Silesia (PCN/CBN/0052/KB1/62/22).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data for the study are available on request from the corresponding author. The data are not publicly available due to the sensitive nature of the participants' data.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DNA	Deoxyribonucleic acid
IR	Infrared
M	Mean
MMP-1	Matrix metalloproteinase-1
ROS	Reactive oxygen species
SD	Standard deviation
SPF	Sun protection factor
UV	Ultraviolet

References

1. Watson, M.; Holman, D.M.; Maguire-Eisen, M. Ultraviolet Radiation Exposure and Its Impact on Skin Cancer Risk. *Semin. Oncol. Nurs.* **2016**, *32*, 241–254. [CrossRef]
2. Raymond-Lezman, J.R.; Riskin, S.I. Sunscreen Safety and Efficacy for the Prevention of Cutaneous Neoplasm. *Cureus* **2024**, *16*, e56369. [CrossRef]
3. Sieniawska, D.; Proszowska, P.; Madoń, M.; Kotowicz, Z.; Orzeł, A.; Pich-Czekierda, A.; Sieniawska, J. Ultraviolet-Protective Clothing and Sunscreen: Sun-Protection for Healthy Skin. *J. Educ. Health Sport.* **2024**, *71*, 51237. [CrossRef]
4. Moyal, D.; Passeron, T.; Josso, M.; Douezan, S.; Delvigne, V.; Seite, S. Formulation of Sunscreens for Optimal Efficacy. *J. Cosmet. Sci.* **2020**, *71*, 199–208.
5. Moloney, F.J.; Collins, S.; Murphy, G.M. Sunscreens: Safety, efficacy and appropriate use. *Am. J. Clin. Dermatol.* **2002**, *3*, 185–191. [CrossRef] [PubMed]
6. Brar, G.; Dhaliwal, A.; Brar, A.S.; Sreedevi, M.; Ahmadi, Y.; Irfan, M.; Golbari, R.; Zumárraga, D.; Yateem, D.; Lysak, Y.; et al. A Comprehensive Review of the Role of UV Radiation in Photoaging Processes Between Different Types of Skin. *Cureus* **2025**, *17*, e81109. [CrossRef]
7. *ISO 24444*; Second Edition. Cosmetics—Sun Protection Test Methods—In Vivo Determination of the Sun Protection Factor (SPF). ISO: Geneva, Switzerland, 2019.
8. Gabard, B.; Ademola, J. Lip sun protection factor of a lipstick sunscreen. *Dermatology* **2001**, *203*, 244–247. [CrossRef]
9. Stolecka-Warzecha, A.; Wilczyński, S.; Pawlus, A.; Lebiedowska, A.; Chmielewski, Ł.; Niezgoda, Z. The Use of Hemispheric Directional Reflectance Method to Verify the Usefulness of Filters Protecting the Skin Against Infrared Radiation. *Clin. Cosmet. Investig. Dermatol.* **2023**, *16*, 2663–2675. [CrossRef]
10. Bożek, M.; Trybała, J.; Lebiedowska, A.; Stolecka-Warzecha, A.; Babczyńska, P.; Wilczyński, S. Assessment of the Sunscreen Properties of Sesame Oil Using the Hemispherical Directional Reflectance Method. *Appl. Sci.* **2024**, *14*, 6545. [CrossRef]

11. Kim, J.; Yeo, H.; Kim, T.; Jeong, E.T.; Lim, J.M.; Park, S.G. Relationship between lip skin biophysical and biochemical characteristics with corneocyte unevenness ratio as a new parameter to assess the severity of lip scaling. *Int. J. Cosmet. Sci.* **2021**, *43*, 275–282. [CrossRef]
12. Dahmer, D.; Scandorieiro, S.; Bigotto, B.G.; Bergamini, T.A.; Germiniani-Cardozo, J.; da Costa, I.M.; Kobayashi, R.K.T.; Nakazato, G.; Borsato, D.; Prudencio, S.H.; et al. Multifunctional Biotechnological Lip Moisturizer for Lip Repair and Hydration: Development, In Vivo Efficacy Assessment and Sensory Analysis. *Cosmetics* **2023**, *10*, 166. [CrossRef]
13. Rahrovan, S.; Fanian, F.; Mehryan, P.; Humbert, P.; Firooz, A. Male versus female skin: What dermatologists and cosmeticians should know. *Int. J. Women's Dermatol.* **2018**, *4*, 122–130. [CrossRef] [PubMed]
14. Cosmetic Products Regulation, Annex VI—Allowed UV Filters. Annex VI, Regulation 1223/2009/EC on Cosmetic Products, as Amended by Regulation (EU) 2024/996, OJ L of 4 April 2024. Available online: https://echa.europa.eu/cosmetics-uv-filters (accessed on 31 August 2025).
15. Kadad, I.M.; Ramadan, A.A.; Kandil, K.M.; Ghoneim, A.A. Relationship between Ultraviolet-B Radiation and Broadband Solar Radiation under All Sky Conditions in Kuwait Hot Climate. *Energies* **2022**, *15*, 3130. [CrossRef]
16. D'Orazio, J.; Jarrett, S.; Amaro-Ortiz, A.; Scott, T. UV radiation and the skin. *Int. J. Mol. Sci.* **2013**, *14*, 12222–12248. [CrossRef]
17. Buechner, N.; Schroeder, P.; Jakob, S.; Kunze, K.; Maresch, T.; Calles, C.; Krutmann, J.; Haendeler, J. Changes of MMP-1 and collagen type Ialpha1 by UVA, UVB and IRA are differentially regulated by Trx-1. *Exp. Gerontol.* **2008**, *43*, 633–637. [CrossRef]
18. Calles, C.; Schneider, M.; Macaluso, F.; Benesova, T.; Krutmann, J.; Schroeder, P. Infrared A radiation influences the skin fibroblast transcriptome: Mechanisms and consequences. *J. Investig. Dermatol.* **2010**, *130*, 1524–1536. [CrossRef]
19. Grether-Beck, S.; Marini, A.; Jaenicke, T.; Krutmann, J. Effective photoprotection of human skin against infrared A radiation by topically applied antioxidants: Results from a vehicle controlled, double-blind, randomized study. *Photochem. Photobiol.* **2015**, *91*, 248–250. [CrossRef]
20. Pourang, A.; Tisack, A.; Ezekwe, N.; Torres, A.E.; Kohli, I.; Hamzavi, I.H.; Lim, H.W. Effects of visible light on mechanisms of skin photoaging. *Photodermatol. Photoimmunol. Photomed.* **2022**, *38*, 191–196. [CrossRef]
21. Lane, B.; Lim, H.W.; Hamzavi, I.H.; Mohammad, T.F.; Kohli, I. Implications of visible light and means of photoprotection. *J. Photochem. Photobiol.* **2023**, *17*, 100203. [CrossRef]
22. He, X.; Jin, S.; Dai, X.; Chen, L.; Xiang, L.; Zhang, C. The Emerging Role of Visible Light in Melanocyte Biology and Skin Pigmentary Disorders: Friend or Foe? *J. Clin. Med.* **2023**, *12*, 7488. [CrossRef]
23. Bernstein, E.F.; Sarkas, H.W.; Boland, P.; Bouche, D. Beyond sun protection factor: An approach to environmental protection with novel mineral coatings in a vehicle containing a blend of skincare ingredients. *J. Cosmet. Dermatol.* **2020**, *19*, 407–415. [CrossRef]
24. Stiefel, C.; Schwack, W.; Nguyen, Y.T. Photostability of cosmetic UV filters on mammalian skin under UV exposure. *Photochem. Photobiol.* **2015**, *91*, 84–91. [CrossRef]
25. Gonzalez, H.; Tarras-Wahlberg, N.; Strömdahl, B.; Juzeniene, A.; Moan, J.; Larkö, O.; Rosén, A.; Wennberg, A.M. Photostability of commercial sunscreens upon sun exposure and irradiation by ultraviolet lamps. *BMC Dermatol.* **2007**, *7*, 1. [CrossRef] [PubMed]
26. Wilczyński, S.; Deda, A.; Koprowski, R.; Banyś, A.; Błońska-Fajfrowska, B. The Use of Directional Reflectance Measurement for in vivo Assessment of Protective Properties of Cosmetics in the Infrared Radiation Range. *Photochem. Photobiol.* **2017**, *93*, 1303–1311. [CrossRef]
27. Mickoś, E.; Michalak, M.; Hartman-Petrycka, M.; Banyś, A.; Babczyńska, P.; Koprowski, R.; Wilczyński, S. Assessing Skin Photoprotection in the Infrared Range: The Reflectance Profiles of Cold-Pressed Plant Oils. *Cosmetics* **2025**, *12*, 80. [CrossRef]
28. Gfeller, C.; Hardie, G.; Shanga, G.; Mahalingam, H. Evaluating the Moisturizing Abilities and Sun Protection Factor of New Lip Balm Formulations. *J. Cosmet. Sci.* **2019**, *70*, 1. [PubMed]
29. Ruvolo, E.; Cole, C.; Rohr, M.; Silverman, J.; Yousefian, O.; Batzer, J.; Lange, N.; Touti, R.; Pouradier, F.; Nogueira, L.; et al. Performance of hybrid diffuse reflectance spectroscopy (HDRS-ISO 23698) methodology for assessment of sunscreen protection in the ALT-SPF Consortium validation study. *Int. J. Cosmet. Sci.* **2025**, *47* (Suppl. 1), 53–77. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.