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Effects of multiple factors on the lasting duration of sunscreens in real life study

Yu han Jiang[1], Yi meng Wang[1], Xue fang Shi[1], Tao Zhang*[1]
Research and Development Center, Bette rWay(Shanghai) Cosmetics Co. Ltd., Shanghai, China

1. Introduction

Sunscreen offers effective photoprotection when evenly and fully spreading on the skin. In real life, its performance is influenced by multiple factors. Consequently, sunscreen may not provide as much sun protection as expected. In a study based on mathematical modelling by Diffey et al, only 10% of the efficiency of UV protection depended on the nature of the sunscreen, while nearly 90% depended on other anthropogenic or environmental factors[1].
However, the effect of these 90% of these factors on sun protection has not yet been systematically studied in vivo experiments. In vivo measurement of SPF and PFA indices is the traditional method of assessing the sun protection of sunscreens. And it has the disadvantages of being invasive, one-time test, unable to be displayed in real time, and unable to be visualized. In addition to this, in vivo methods and measurement indicators to verify the efficacy of sunscreen products are relatively homogeneous, and most of them are aimed at evaluating the results rather than the external causes. Wang Shan et al. investigated the protective effect of a baby sunscreen by measuring the melanin and erythema values of the skin, water content and transdermal water loss and assessed the results of the changes in the skin parameters without measuring the factors leading to the duration of sun protection[2]. Corinne Granger et al. also examined the outdoor sun protection efficacy of an Oil-in-Water sunscreen product by assessing the skin erythema index[3]. Eduardo Ruvolo et al. utilized a novel, rapid, non-invasive Hybrid Diffuse Reflectance Spectroscopy (HDRS) method to evaluate the persistence of protection by 80 minutes water-resistant sunscreen formulation with and without re-application, and with and without sweat-inducing activity over 6 hours[4]. This study did not compare differences in the degree of influence of individual factors.
In order to isolate the variables and quantitatively analyze the lasting duration of sunscreens in the real life, we recruited 12 Chinese to explore how factors like application time, skin physiological parameters, environmental and activity affect the lasting duration of sunscreen on the face. Through skin measurement equipment, image analysis software and data processing, we try to figure out how much impact of single factor contributes to the fade of sunscreens.

2. Materials and Methods

2.1 Materials

A W/O sunscreen lotion SPF50+ PA++++ (shake well before use), facial tissue, 2 mL disposable syringe, timer, Vplus® Pro, Sebumeter® SM 815, Corneometer® CM825, Image-Pro® Plus 7.0 (IPP).

2.2 Methods

A total of 12 Chinese (10 females, 2 males), aged 18-38 years old, with 6 oily skin type and 6 dry skin type. During recruitment, oily skin subjects were defined as those with forehead sebum levels >120 measured by Sebumeter®, while dry skin subjects required forehead sebum levels <80 and zygomatic hydration <45 measured by Corneometer®. All measurements were conducted under unwashed morning conditions. Everyone was asked to participate in two separate days in a constant temperature and humidity lab (21±1 °C，50±10% RH) and outdoors in the shade (sunny days of September in Shanghai). When in outdoors, each subject was asked to do 40 mins of moderate intensity exercise for sweating. After applying a quantitative amount of sunscreen (0.6 mL) to the face at 20 mins, 1 h, 2 h, 4 h, and 6 h, images were captured under UV light (center wavelength of 365 nm) using Vplus® Pro, and half of the face was wiped with a tissue before image capture. IPP was used to output image parameters to quantify the sunscreen's lasting duration. Correlation analysis and comparison analysis were applied to evaluate the relationship and difference of multiple factors.

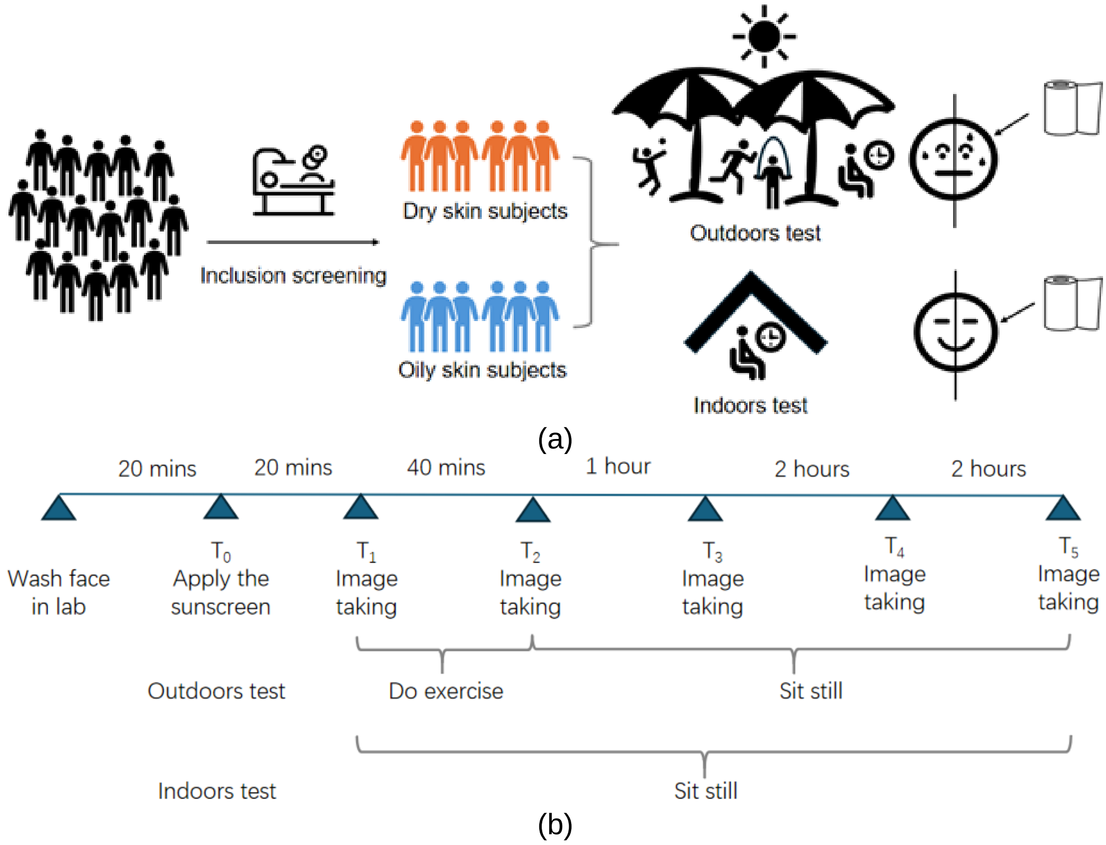


Figure 1. Test process: (a)Work flow; (b)Timeline of check points

3. Results

3.1 Subject grouping and separation of variables

Each subject has 4 images of half-face, namely the unwiped half-face in indoors test, the wiped half-face in indoors test, the unwiped half-face in outdoors test, and the wiped half-faces in outdoors test. We divided 48 half-faces images into five groups, and assuming that unwiped half-faces of dry skin subjects in indoors test was the control group. With all other unknown influences being equal, we set all half-faces to be a group used to observe the effect of time, set all wiped half-faces be a group used to observe the function of wiping, set all half-faces of oily skin subjects to be a group used to observe the function of sebum secretion, and set all half-faces in outdoors test to be a group used to observe the function of sweating.

Table 1. Grouping of subjects

Classification		**Group items**				
Skin type	**Image items**	**Control group**	**Time**	**Wiping**	**Sebum secretion**	**Sweating**
Dry	Unwiped half-faces indoors	✓	✓			
	Wiped half-faces indoors		✓	✓		
	Unwiped half-faces outdoors		✓			✓
	Wiped half-faces outdoors		✓	✓		✓
Oily	Unwiped half-faces indoors		✓		✓	
	Wiped half-faces intdoors		✓	✓	✓	
	Unwiped half-faces outdoors		✓		✓	✓
	Wiped half-faces outdoors		✓	✓	✓	✓
Number of half-faces in each group		**6**	**48**	**24**	**24**	**24**

3.2 Data processing

Each subject had 6 check points during the test, 20 minutes after cleansing the face and sitting in a constant temperature and humidity room (T_0), 20 minutes after applying sunscreen (T_1), 1 hour later (T_2), 2 hours later (T_3), 4 hours later (T_4), and 6 hours later (T_5). Facial Images under a UV light source were captured at each check point, and the luminance values L* of AOI were analyzed using IPP. Define ΔL to express the fade of sunscreen at a specific check point. Figure 2 represents the post-statistical data ΔL of each group. We set the 50% as the criteria line of ΔL and assume the sunscreen is devastated under the specific condition when ΔL>50%.

$$\Delta L = \frac{L_t - L_1}{L_t - L_0} \times 100\%$$

Where,

L_t as the L* value of image at a given check point, t could be 2/3/4/5,

L_1 as the L* value of image at T_1,

L_0 as the L* value at T_0.

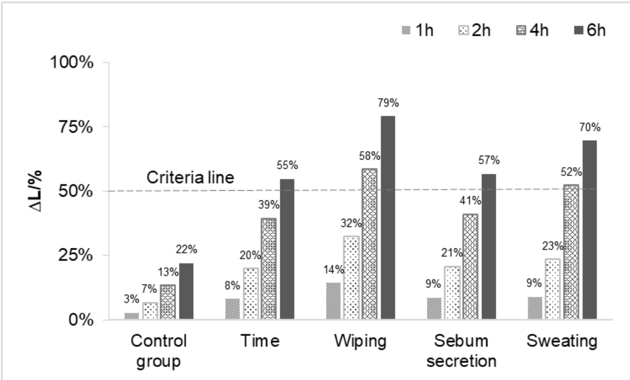


Figure 2. The average of ΔL in each group.

3.3 Correlation analysis and comparison analysis

According to Figure 2 above, the control group showed good sun protection within 6 hours. Sunscreen in time and sebum secretion groups was devastated until 6 hours, wiping and sweating groups until 4 hours. To quantify these differences, we performed a correlation analysis of the data to derive a correlation coefficient of each subject in the same group between ΔL vs. Time. The average and standard deviation of the correlation coefficient separately indicates the mean level and degree of dispersion of the data. Further, we defined the additive difference between control group and the observation group as the total impact coefficient of the corresponding single factor. The ranked degree of impact on the sunscreen duration were wiping (3.41%), sebum secretion (3.06%), time (2.61%), and sweating (2.20%).

$$\mathrm{R} = (\mathrm{dif}\,\bar{\mathrm{r}} + \mathrm{dif}\,\mathrm{r_{sd}}) \times 100\%$$

Where,

R as the total impact coefficients,

$\mathrm{dif}\,\bar{\mathrm{r}}$ as the difference of $\bar{\mathrm{r}}$ between control group and observation group,

$\mathrm{dif}\,\mathrm{r_{sd}}$ as the difference of $\mathrm{r_{sd}}$ between control group and observation group.

Table 2. Data results of correlation analysis

Parameters	Control group	Time	Wiping	Sebum secretion	Sweating
$\bar{\mathrm{r}}$	0.9829	0.9686	0.9659	0.9654	0.9689
$\mathrm{r_{sd}}$	0.0161	0.0279	0.0332	0.0292	0.0241
$\mathrm{dif}\,\bar{\mathrm{r}}$		0.0143	0.0170	0.0175	0.0140
$\mathrm{dif}\,\mathrm{r_{sd}}$		0.0118	0.0171	0.0131	0.0080
R/%		2.61	3.41	3.06	2.20

3.4 Significant analysis

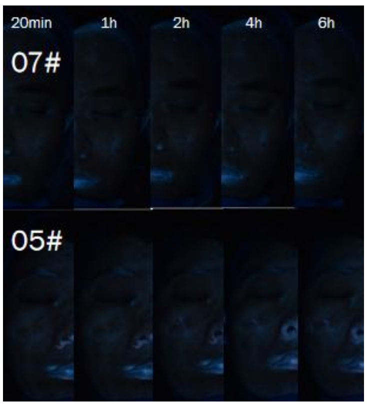
In order to investigate at which check point that a single factor can make a significant difference in the sunscreen duration, the ΔL at different check point were analyzed using Paired-T test. For indoors test, tissue wiping began to have a significant impact on sunscreen duration after 1 h for both oily and dry skin subjects. For outdoors test, tissue wiping had a significant impact on sunscreen duration for oily skin until 6 h, while for dry skin, it had earlier impact at 1h. After 1 h, sweating significantly affected the duration on dry skin, but had no such effect on oily skin within 6 h. The duration of sunscreen also showed significant differences between oily and dry skin subjects in indoors test within 6 h, while no significant differences in outdoors test.

Table 3. Significance level results

Skin type	Dry			Oily				
Controlled variables	Half-faces indoors	Half-faces outdoors	Half-faces unwiped	Half-faces indoors	Half-faces outdoors	Half-faces unwiped	Half-faces unwiped indoors	Half-faces unwiped outdoors
Observed variables	Wiped vs. Unwiped	Wiped vs. Unwiped	Sweating vs. No-sweating	Wiped vs. Unwiped	Wiped vs. Unwiped	Sweating vs. No-sweating	Dry skin vs. Oily skin	Dry skin vs. Oily skin
1h	*	n.s	n.s	*	n.s	n.s	*	n.s
2h	*	*	*	*	n.s	n.s	*	n.s
4h	*	*	*	*	n.s	n.s	*	n.s
6h	*	*	*	*	*	n.s	*	n.s

3.5 Influence of skin roughness on the duration of sun protection

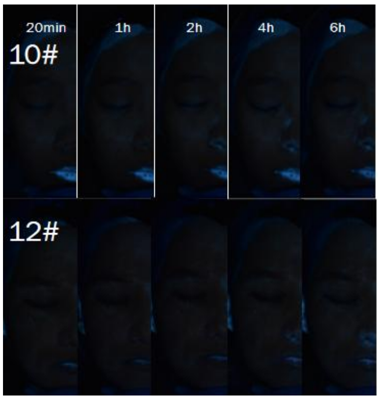
From the images under the UV light, we also found that outdoor sweating showed that rougher skin with more pores sped up sunscreen fade for both dry and oily skin subjects. Figure 3 shows the facial images of two oily skin subjects, it can be seen that in outdoor test without wiping, facial sunscreen persistence of 05# is lower than that of 07#, while for in indoor test, there is no significant difference between that of two subjects. We further explored whether there were other factors contributing to this phenomenon. The images of positive white light show that 05# has more larger pores than 07#. This may lead to increased roughness of the skin, further affecting the evenness of sunscreen application on the face thus further affecting its duration. This phenomenon can also be seen in the images of the two dry skin subjects in Figure 4. And this phenomenon is only shown in the case of exposure to high temperature sweating.



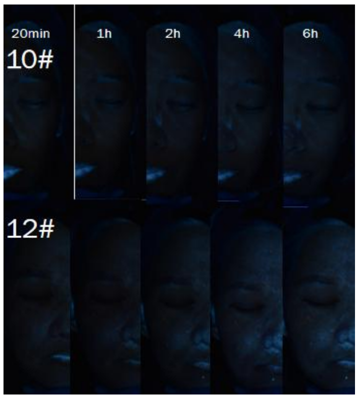
(a)

(b)

Figure 3. The facial image of 07# and 05# oily skin subjects under the UV light: (a) unwiped face in indoors test; (b) unwiped face in outdoors test



(a)



(b)

Figure 4. The facial image of 10# and 12# dry skin subjects under the UV light: (a) unwiped face in indoors test; (b) unwiped face in outdoors test

4. Discussion

After 12 subjects with different skin types have finished the test when subjected to controlled environmental exposures and behavioral interventions, the duration of sunscreen applied to their faces varied. The ranked effects of correlation coefficients on the lasting duration of sunscreen were wiping (3.41%), sebum secretion (3.06%), time (2.61%), and sweaty (2.20%). That is, the physical friction of external objects has the greatest effect on the sunscreen duration. Sweating had the least effect on the sunscreen duration, probably because the test sample is a Oil-in-Water dosage form. From a much broader group, the passage of time had a less impact on the sunscreen duration, but greater than sweating.

Tissue wiping had a more significant impact on oily skin's sunscreen duration in indoor test than in outdoor test. This proves sweating counteracted the effects of sebum secretion and tissue wiping on sunscreen duration. Outdoor sweating showed that rougher skin with more pores sped up sunscreen fade for both oily and dry skin type.

5. Conclusion

In this study, we explored the real-life impacts of multiple factors on sunscreen's lasting duration outside the lab. By setting various test scenarios and behaviors, targeting different skin physiological types, and applying different interventions, we systematically evaluated these factors affecting actual protective efficacy of sunscreens. Correlation and comparison analysis showed that for oily skin, sebum secretion and wiping were key factors affecting sunscreen duration, while for dry skin, it was wiping and sweating. Additionally, we found that skin roughness and pore number as new factors accelerated sunscreen fade for both oily and dry skin. These findings offer critical insights for sunscreen formulation development, beyond standard laboratory testing, it is essential to integrate simulations of real-life environmental variables and optimize performance indicators such as film-forming capability, friction resistance, and sweat resistance, ultimately delivering sunscreen solutions that better align with consumers' practical needs.

6. References

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