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“Comparative analysis of the coverage, uniformity, application time and product consumption of different types of sunscreens”

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1 ARTHA Research

1. Introduction

Photoprotection plays a fundamental role in preventing the harmful effects of ultraviolet (UV) radiation, including photoaging, hyperpigmentation, and the increased risk of skin cancer. The effectiveness of sun protection is directly related to the type of sunscreen chosen, the method of application and the amount used. The internationally recognized standard for sunscreen application is 2 mg/cm² [1]. However, numerous studies have shown that sunscreens are often applied incorrectly, in quantities well below those required to achieve the Sun Protection Factor (SPF) indicated on the label. This inadequate application may be influenced by sensory attributes, product usability and user experience [2].

Several factors related to the active ingredients in sunscreens — such as skin feel, cost and compatibility with different skin types — directly influence adherence to sunscreen use. These elements affect whether individuals apply the product consistently and correctly, and whether they choose to repurchase it. Therefore, one of the main goals in sunscreen formulation is to ensure efficacy while also minimizing cost, reducing the potential for irritation and delivering a pleasant sensory experience to promote continuous use [3].

In addition to formulation components, the presentation format — such as stick, liquid, powder or spray — can significantly affect the application method and the effectiveness of skin coverage [4]. Different formats may vary in terms of coverage uniformity, speed and practicality of application, and product consumption, all of which directly impact user satisfaction and

continued use. Understanding how these factors interact is essential for optimizing photoprotection recommendations, taking into account the diverse profiles and needs of consumers.

This study aims to evaluate the effectiveness of four sunscreen formats — stick, liquid, powder and spray — based on three main criteria: (1) practicality of application; (2) product consumption; (3) uniformity of coverage. In addition to objective evaluations, qualitative data were collected through questionnaires completed by volunteers, addressing subjective perceptions such as ease of use, comfort and skin sensation after application.

The results obtained from this study may support the development of more effective and sensorially acceptable formulations, contributing to improved adherence to daily sunscreen use. Furthermore, the findings can assist cosmetic and healthcare professionals in making personalized product recommendations, aligned with the preferences and needs of individual users. It is expected that this research will reinforce the importance of product format in the practical effectiveness of photoprotection, encouraging innovation that reflects real-world consumer behavior.

2. Materials and Methods

Subjects recruitment

A total of 80 healthy volunteers (aged 20–50 years; Fitzpatrick skin phototypes I–VI), all regular users of sunscreen, were recruited for the study. Participants were randomly assigned to apply one of four sunscreen formats: liquid, stick, spray or powder. Each participant used only one type of sunscreen throughout the study. Individuals with a known history of allergy or sensitivity to any of the sunscreen formulations under investigation were excluded. No additional exclusion criteria were applied regarding ethnicity, occupation or other demographic characteristics.

All volunteers completed a pre-screening questionnaire indicating the type of sunscreen they commonly used. To eliminate any residual product that could interfere with the assessment, participants were instructed to cleanse their face using a makeup-removing oil. Standardized UV-filter photographs were taken prior to sunscreen application using a controlled imaging device.

Participants then applied the assigned sunscreen themselves, using a mirror, following their usual method of application. Bottles were weighed before and after application to determine the amount of product used and the time taken for application was recorded. After application, a second set of standardized UV photographs was taken to evaluate product uniformity, coverage and application effectiveness. Finally, all participants completed a self-

assessment questionnaire regarding the sensory and practical aspects of the sunscreen they used.

Image Analysis

The images were processed using ImageJ software (NIH, Bethesda, MD, USA). Initially, each image was converted to grayscale (8-bit), and then a standardized threshold was applied to segment the areas covered by the sunscreen (dark regions) from the uncovered areas (lighter regions). After segmentation, the "Analyze Particles" tool was used to calculate the area covered by the product. The total area was manually defined with a region of interest (ROI) encompassing only the exposed facial surface. The coverage percentage was calculated by the ratio of the darkened area (indicating the presence of sunscreen) to the total area of the ROI, expressed as a percentage. This method enabled an objective and reproducible analysis of the uniformity and extent of sunscreen application.

3. Results

All 80 participants were randomized to apply only one type of sunscreen: liquid ($n=20$), stick ($n=20$), spray ($n=20$) and powder ($n=20$). Regarding the average application time, the spray and liquid sunscreens were considered the fastest, with average times of 30.42 seconds and 44.27 seconds, in sequence. In contrast, the powder and stick sunscreens required more time to achieve what participants considered a satisfactory coverage, with average times of 56.17 seconds and 1 minute and 4 seconds, respectively.

As for product consumption, it was observed that in all types applied, the amount of product did not reach the internationally recommended value of 2 mg/cm^2 . The spray format showed the highest consumption, with an average of 1.08 mg/cm^2 . The stick sunscreen had an average consumption of 0.2908 mg/cm^2 . The liquid sunscreen had a consumption of 0.632 mg/cm^2 . The powder sunscreen, on the other hand, was the most economical in terms of quantity used, with an average consumption of 0.0692 mg/cm^2 .

The coverage analysis, conducted using software, revealed significant differences between the tested types. The spray formulation showed the highest average uniformity, with 32% coverage (Figure 1). The liquid sunscreen, on the other hand, showed an average coverage of 29% among the participants.

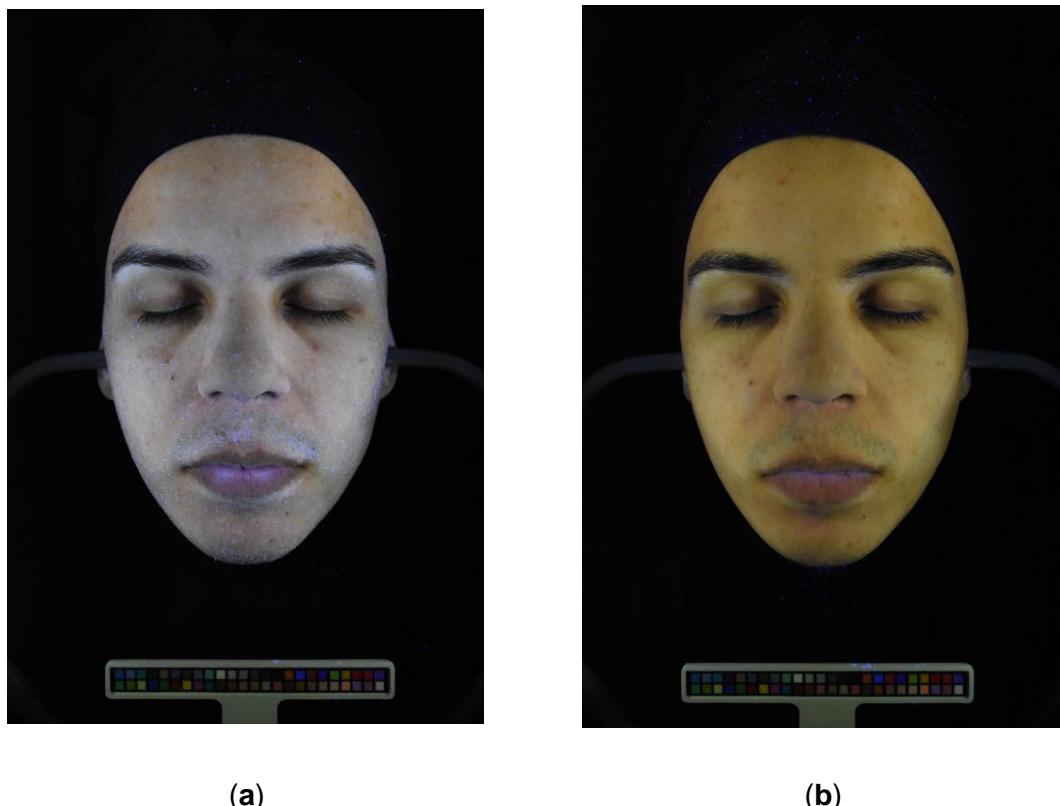


Figure 1. Photo of UV filter spray sunscreen. (a) Participant with clean face taking the standardised photo, before applying sunscreen; (b) Participant after applying sunscreen spray. The amount of product applied was 1.107 g, which covers approximately 553.5 cm² of skin.

In contrast, the stick sunscreen demonstrated the lowest ability to provide an even application, with an average of 25% coverage (Figure 2). The powder sunscreen, in turn, presented an average of 30% coverage under the UV filter. However, this result should be interpreted with caution, as it had the lowest consumption average and the translucent formulation may not have been fully detected by the optical capture of the system used, potentially reflecting more the skin's uniformity rather than the actual deposition of the product.

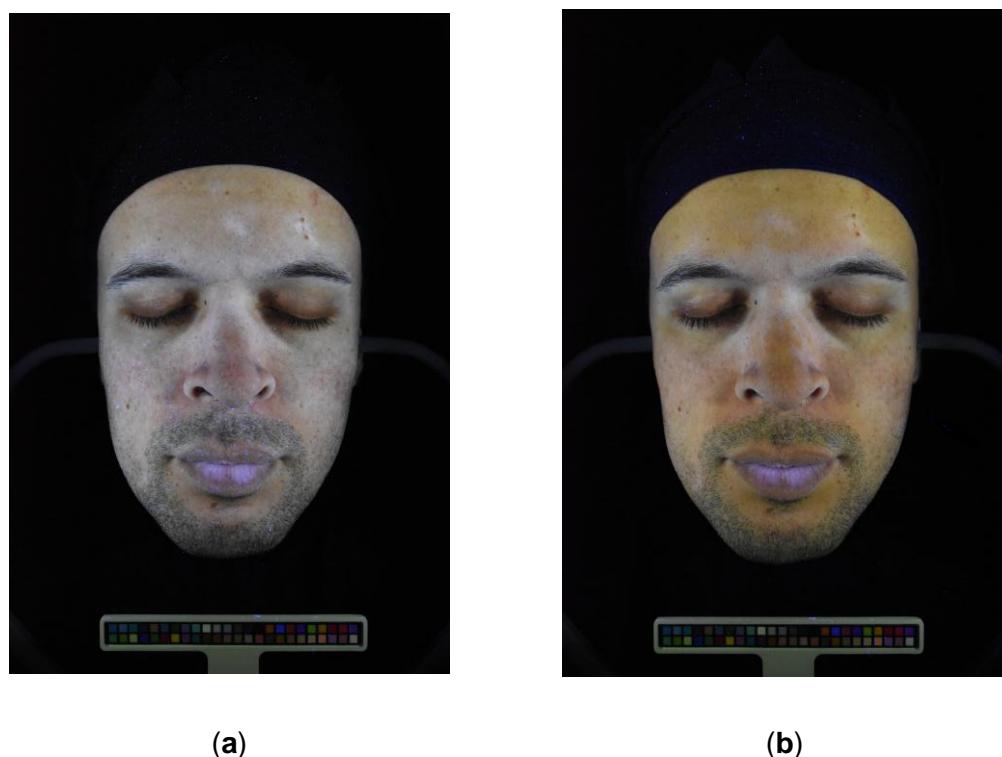


Figure 2. Standardised photo with UV filter before and after applying the sunscreen stick. (a) Participant with clean face taking the standardised photo, before applying sunscreen; (b) Participant after applying sunscreen stick. The amount of product applied was 169 mg, which covers approximately 84,5 cm² of skin. Areas of the face with a lack of coverage can be seen, indicating insufficient application of sunscreen in certain areas.

In the questionnaire conducted after use, 90% ($n=18$) of participants who used the liquid sunscreen reported a feeling of lightness and quick absorption. In the stick group, 50% ($n=10$) mentioned a denser texture but associated this characteristic with a more precise and localized application. Regarding the powder sunscreen, half of the users (50%, $n=10$) also noticed lightness during use; however, 75% ($n=15$) indicated that the product did not provide satisfactory absorption. The spray sunscreen, on the other hand, was negatively evaluated by a large portion of the participants: 80% ($n=16$) described the texture as dense and with the formation of a sticky residue on the skin, while 95% ($n=19$) stated that the product was not adequately absorbed.

4. Discussion

The results of this study provide a comprehensive view of the differences in both effectiveness and user experience among four types of sunscreens (liquid, stick, spray and powder), focusing not only on coverage but also on application feel, absorption and product usage.

Regarding application time, spray and liquid sunscreens stood out for their speed, with mean times of 30.42 and 44.27 seconds, respectively. The ease and agility of these products are appealing, especially for individuals seeking practicality in daily use. In contrast, stick and powder sunscreens required more time to achieve coverage considered satisfactory by participants, reflecting the need for greater attention and effort during application.

Product consumption was a crucial point in the analysis, as none of the sunscreen types reached the internationally recommended application rate of 2 mg/cm^2 . The spray formulation came closest to this recommendation (1.08 mg/cm^2), yet still fell short of the ideal amount for effective protection. Stick, liquid and powder sunscreens showed considerably lower usage, which may indicate that participants were applying less product than necessary to ensure adequate sun protection.

In terms of coverage, the objective analysis conducted using the ImageJ software revealed marked differences among the sunscreen types. The spray sunscreen achieved the highest mean uniformity of coverage (32%), suggesting good product distribution, which is essential for effective protection against UV radiation damage. However, despite this relatively good coverage, the spray was poorly rated by participants due to its dense texture and the sticky residue left on the skin, compromising user comfort and absorption. These factors suggest that the initial coverage provided by the spray may be undermined by poor adherence to the skin, resulting in less durable protection.

The stick sunscreen, which showed the lowest mean coverage (25%), was noted for its precision and localized application — an advantage in specific facial or body areas. However, this feature may have contributed to lower overall coverage, as the product's density and the need for more careful application required more time and effort from participants to ensure adequate distribution. This behavior may have affected the amount applied.

The liquid sunscreen, with a mean coverage of 29%, demonstrated intermediate performance among the tested products. Its fast absorption and light feel were well received, but the amount applied was lower than the ideal to reach the recommended dose of 2 mg/cm^2 , raising concerns about the effectiveness of protection. Although participants appreciated the lightweight sensation, rapid absorption may have led to incomplete application in some areas, affecting uniform coverage.

The powder sunscreen, while presenting a mean coverage of 30%, was the most economical in terms of usage (0.0692 mg/cm^2). However, the low product consumption and translucent formulation may have hindered the accurate detection of coverage by the optical capture system. Additionally, 75% of participants reported dissatisfaction with the powder's

absorption, suggesting suboptimal distribution on the skin. Its lightweight feel may have led users to apply it insufficiently, impairing the effectiveness of sun protection.

5. Conclusion

This study highlights that the effectiveness of sunscreen products is influenced not only by their coverage performance but also by user-related factors such as sensory perception, application time, absorption and product usage. Although the spray formulation demonstrated the highest mean coverage, it was poorly rated due to unpleasant texture and inadequate absorption, which may compromise long-term protection. Stick and powder sunscreens allowed for more precise application but showed lower coverage uniformity and limited absorption, potentially reducing their protective efficacy. The liquid sunscreen achieved a favorable balance between user comfort, absorption and moderate coverage; however, the suboptimal amount applied by participants fell short of the recommended 2 mg/cm^2 , which may limit its effectiveness. These findings underscore the importance of selecting sunscreen formulations that offer both user acceptability and adequate photoprotection. Furthermore, educating consumers on proper application techniques and adequate dosing is essential to enhance the real-world effectiveness of all sunscreen types.

6. References

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