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Major Article

The topical application of different galenic formulations can alter the thermographic images of skin: Limitations for public thermal screening on infection control situations

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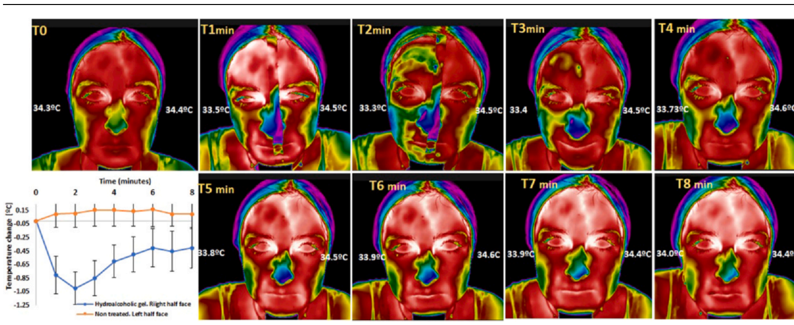
Graphical abstract



The effect of different galenic formulations on fast thermal changes in the skin was studied by thermographic images. Example of the evolution of face thermal changes after application of hydroalcoholic gel on the right half of the face of a volunteer. A significant decrease of more than 1.0°C was observed just 1 minute after hydroalcoholic gel application that recovered after 8 minutes. Experiments on the back of volunteers showed a mean thermal drop of more than 2°C. It could be possible to detect false negative data in the readings of patients screened thermically.

Key Words:
Skin temperature
Thermographic camera
Cosmetics
Sunscreens

Background: To analyze whether the application of topical formulas as cosmetics or sunscreens could affect the skin thermographic readings in terms of infection control in pandemic situations.
Methods: The temperature of the skin of the dorsal region of the back and the face of 20 volunteers was followed after the application of 6 different types of gels, sunscreens, and make-up under controlled

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Conflicts of interest: None to report.

Ethics approval and consent to participate: This is an experimental study with no intrusive techniques based on photography and commercial cosmetics compounds used. The University of Málaga Institute of Biomedicine (IBIMA) Research Ethics Committee has confirmed that no ethical approval is required.

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temperature and humidity conditions. High-resolution thermographic images were analyzed to calculate the temperature of treated skin compared to skin free of topical products.

Results: The application of hydroalcoholic gel resulted in a mean drop of more than 2°C just after 1 minute followed by organic sunscreens until 1.7°C. Recovery was observed progressively until minute 9. Color make-up type formulas, rich in iron oxide as well as sunscreens with mineral filters had little or no effect on the skin thermal response.

Conclusions: It is possible to alter the skin temperature almost immediately by using hydroalcoholic gels and sunscreen cosmetics. So, it is possible to produce false negative data in the readings of patients screened thermically.

BACKGROUND

Today's population mobility is so rapid that in an interval of a few hours is possible to change city, country, even continent. So, it means that diseases are capable of spreading at high speeds also as happened with COVID-19 and other pandemic situations as monkey fever. It is, therefore, essential to develop technologies that respond to human needs for early action and detection of these disease-carrying flows.

Among all the technologies, since all structures or materials on earth emit heat as thermal energy, infrared thermography (IT) is a technique that allows to visualize the heat given off by any material, as the human body, by recording their emitted infrared radiation.[1,2] The first IT cameras were developed in 1958 for military use during the Korean War. The thermal imaging cameras have been used in all fields of human life, and their use is so extended that the design allows to use portable cameras with a very high resolution and easy one-handed operation.[3,4]

The physical principle of IT operation is given by the emission of electromagnetic energy that anybody emits when subjected to external energy levels, and that the camera can detect the temperature of that object without the need for physical contact.[2] The passage of blood through the vascular system (arteries, veins, and capillaries) causes the release of heat energy that can be quantified by devices designed for this purpose. The dissipation of heat (temperature) occurs in the skin, making this extensive organ the object of measurement by thermographic cameras.[5,6] IT has recently multiple applications in medicine in many different areas.[7–10]

Ng et al[11] studied the effectiveness of thermography for mass fever detection, where thermograms of the neck and facial regions were recorded. They found that the sensitivity of the thermal imaging methodology was similar to that of self-reported fever cases and concluded that it is an effective tool for rapid, noncontact fever screening. The outbreak of pandemics since the 20th century and continuing into the beginning of the 21st century, such as severe acute respiratory syndromes (SARS) and avian influenza get into a general global alarm. So, the use of IT-based techniques for mass fever screening has been extended.[12–14]

Recently, IT has been successfully used for mass fever screening in subjects with COVID-19, a highly infectious disease caused by the SARS-2 coronavirus.[15] Detection of potentially infected subjects is a major requirement for the prevention of mass spread of COVID-19. Ng[11] studied the effectiveness of IT in mass fever detection, concluding that elevated body temperature is one of the most common syndromes of many infectious diseases; obviously, these now include COVID-19 and therefore, IT is a powerful tool for the initial detection of subjects even in COVID-19 patients with minimal symptoms.[16] The most important fact is that by means of this IT methodology illness screening can be performed in an automated way for many people in a very short period of time,[17] for example, in the control of access to airports, large companies, mass entertainment, and cultural events, etc. as a very important control tool for controlling people mobility and COVID dissemination.[18]

This tool for mass and rapid detection of body temperature could be exposed to different limitations since our body temperature varies rapidly as we can appreciate after the simple application of water or after the typical use of hydroalcoholic gel in hand disinfection, as a consequence of the dissipation of the alcohol that evaporates and produces a thermal change in the skin. Therefore, one of the hypotheses of the present study is that the use of different "normal way of life" events could alter body temperature in subjects with fever after the application of cosmetic products.

Therefore, the aim of our study was to investigate the thermographic response as temperature changes of the skin, both on the face and on the back, after the application of a series of galenic formulations as hydroalcoholic gel and sunscreens as well as "tinted makeup", to find out whether it is possible to alter this thermographic reading, which could alter the potential mobility restrictions imposed during the COVID-19 pandemic.

METHODS

Type of study and selection of volunteers

An experimental study was designed in order to analyze the effect of short-term skin temperature changes (minutes) by means of thermal photography after the use of different topical galenic formulas on the skin. A total of 20 volunteers (14 women and 6 men) were selected who were of legal age and presented no characteristics or potential allergies to the products. Before starting the study, the methodology to be followed in the thermographic readings as part of this experimental study was explained to each volunteer and each of them gave their written consent to participate in the study. Each volunteer underwent a medical history and was specifically asked about the presence of dermatological or systemic diseases that could alter the blood flow in the area to be explored during the measurement of the thermographic readings. People who presented at the moment of the experiments some signs of temperature alterations (fever or suspected infectious conditions) and people with potential sensitivity to cosmetics were ruled out.

The technique of measuring thermographic readings is qualified as nondestructive testing,[5] as well as the application of cosmetics, are noninvasive technique. So, all bioethical conditions that apply to any test on humans were considered as included in the Declaration of Helsinki of the World Medical Association of 1964 (last revision: 2013) as well as the regulation (EC) No 1223/2009 of the European Parliament for cosmetics purposes.[19] The University of Málaga Institute of Biomedicine Research Ethics Committee confirmed that no ethical approval was required.

The thermal images were taken by a FLIR T540 camera (Teledyne FLIR Co). This camera has a 464 × 348-pixel thermal sensor, a thermal sensitivity < 30 mK, 42° × 32° field of view, 30 Hz frame rate, a focusable lens for adjusting thermal images, a temperature detection range from −20 to 1,500°C, a photo and video capture, spot temperature, high and low temperature, threshold mode, and 5 color palettes. It is a highly portable, versatile, and durable thermal imaging camera that connects directly to a computer or smartphone. This device translates thermal energy (infrared light) into a visible image. The FLIR T540's narrow 42-degree field of view is designed for both indoor and outdoor use.

The measurements of thermographic readings were made in a temperature and humidity-controlled room and all the volunteers were acclimatized sit in the position of measurements for 30 minutes prior to the assays. So, thermal alterations to mobility were controlled. Researchers remained all the time in a quiet position together with the volunteers in order to maintain stablish environmental control.

Thermal images analysis

Two body parts were used for the thermal analysis. First, the analysis on the back in which, 6 different galenic formulations for topical purposes were measured in parallel in each of the 20 volunteers. The cosmetic formulations used for the back were: P1—hydroalcoholic gel, P2—sunscreen ISIDN photoprotector transparent (20% alcohol spray) SPF 50+, P3—sunscreen Heliocare 360 water gel (without color) SPF 50+, P4—sunscreen Heliocare 360 photoprotector with color (oil-free gel) SPF 50+, P5—sunscreen AVENE 100% mineral photoprotector SPF 50 and P6—simple cream "make-up" highly tinted based on the iron oxide minerals and without sunscreen filters. These were compared parallelly and with respect to untreated skin by applying them to 6 adjacent areas on the back (Fig 1A, B).

After the back experiment, a second "normal way of life" assay was performed on the subject's face simulating real hydroalcohplic gel, as well as different application conditions and thermographic measurements. Each volunteer received instructions for self-application of the product in a generous layer on the right side of the face except the eye area. For this real-life test, 4 of the galenic formulas of the back experiment were selected. They corresponded to "normally used" by consumers (P1—hidroalcololic gel, P3—organic water gel–based sunscreen, P5–100% mineral sunscreen, and P6—color make-up formula. For each volunteer, only 1 product was used in order to avoid skin basal thermal variations from one to another product. Thus, the 4 products were analyzed in facial skin in groups of 5 individuals and therefore, forming 4 groups of volunteers for this purpose.

Protocol

For back experiment, Each volunteer had an intervention area on the upper part of the back marked with a predesigned adhesive paper covering 6 identical squares of $3 \times 3\ cm^2$ surface. Taking the measurements on the back ensured an anatomically homogeneous application on the skin and in a plane perpendicular to the measurement axis, thus guaranteeing a good comparison between products. After 10 minutes of application of the adhesive tape, ensuring no thermal alterations by skin manipulation, the basal thermographic readings were taken from the subjects prior to application of the creams or gels on the back, specifically in the 6 areas designed. Subsequently, the creams and gels were applied at a dose of $2\ mg/cm^2$ for a total of 18 mg/square, weighed on a Sartorious BL-120S precision balance (Sartorius Lab GmbH). Immediately after the application of the product on the back, a second reading was taken with the thermographic camera situated in a fixed tripod at a distance of 70 cm from the back of the sit volunteer. The application of the products was carried out at 1-minute intervals. At time 0, P1 was applied. P2 was applied 1 minute later, P3 1 minute later (as shown in Fig 2), and sequentially for the 6 different products. In order to record the evolution of the thermal changes on the back after the application of different topical galenic formulations all the photographs were taken at 1 minute intervals just after the application of the first product. For example, product 3 was applied 2 minutes after the application of product 1 but the sequence of photographs at intervals of 1 minute was maintained from the beginning until 14 minutes after the application of the last product (see Fig 2 as an example of to show the evolution of thermal changes after the application of each product until the first 14 minutes of the experiment).

In the case of the face experiment, each volunteer self-applied the selected topic formula of the 4 assayes 1 (hydroalcoholic, organic water gel sunscreen, mineral sunscreen, color makeup). They were instructed to apply a generous layer on the right side of the face except the eye area. Immediately after applying the product, a new photo was taken and continued at 1 minute intervals up to 8 minutes in duration. Images of an example of the normal and thermal photo of the face 2 minutes after the application of the product can be observed in Figure 1C, D.

Image analysis

Once the thermographic readings were recorded, image analysis software (FLIR Tools 6.4) process each of the images. This allowed us, in the case of the back, to delimit the 6 previously designed intervention zones, and thus determine the maximum, minimum, and average temperature values of each of these zones (Fig 1A, B). We also processed the thermographic images of the face, dividing it into 2 main zones, half right (treated) and left side (nontreated). In each half side of the face, 4 measurements were performed: delimited forehead zone, eye zone, cheekbone or cheek zone, and, finally, a fourth zone that includes the 3 previous zones together as global half-face measurement. For each of the 4 face zones, the maximum, minimum, and mean values for each of these areas were taken as shown in Figure 1C, D.

Statistics

For each volunteer, and for each product, a photograph was taken at each time interval both in the back and the face experiment. The results were represented as the mean ± standard deviation of the color scale values for each area of the total of the 20 volunteers analyzed on the back and 4 groups of 5 volunteers in the face experiment. The mean values at each time measurement were compared with each other with respect to the initial value by repeated samples analysis of variance. Regression analysis of the thermal decrease on the face and back skin with respect to the basal temperature has been included. The correlation coefficients for the variables have been also included.[20] The significance level was $P < .05$ and was performed using the SPSS v21 statistical software (IBM). Trend graphs were carried out using Microsoft Excel spreadsheets, office 2019 version.

RESULTS

Thermal analysis of back

Figure 2 shows an image as an example of the sequential application of the 6 products (1 minute intervals) and in which the changes in color can be observed as time elapses for each of the products tested. The averages of the thermographic recordings obtained on the backs of the volunteers after the application of 6 different cosmetic or sun protection products are shown in Figure 3. The application of the hydroalcoholic gel (P1) on the back resulted in

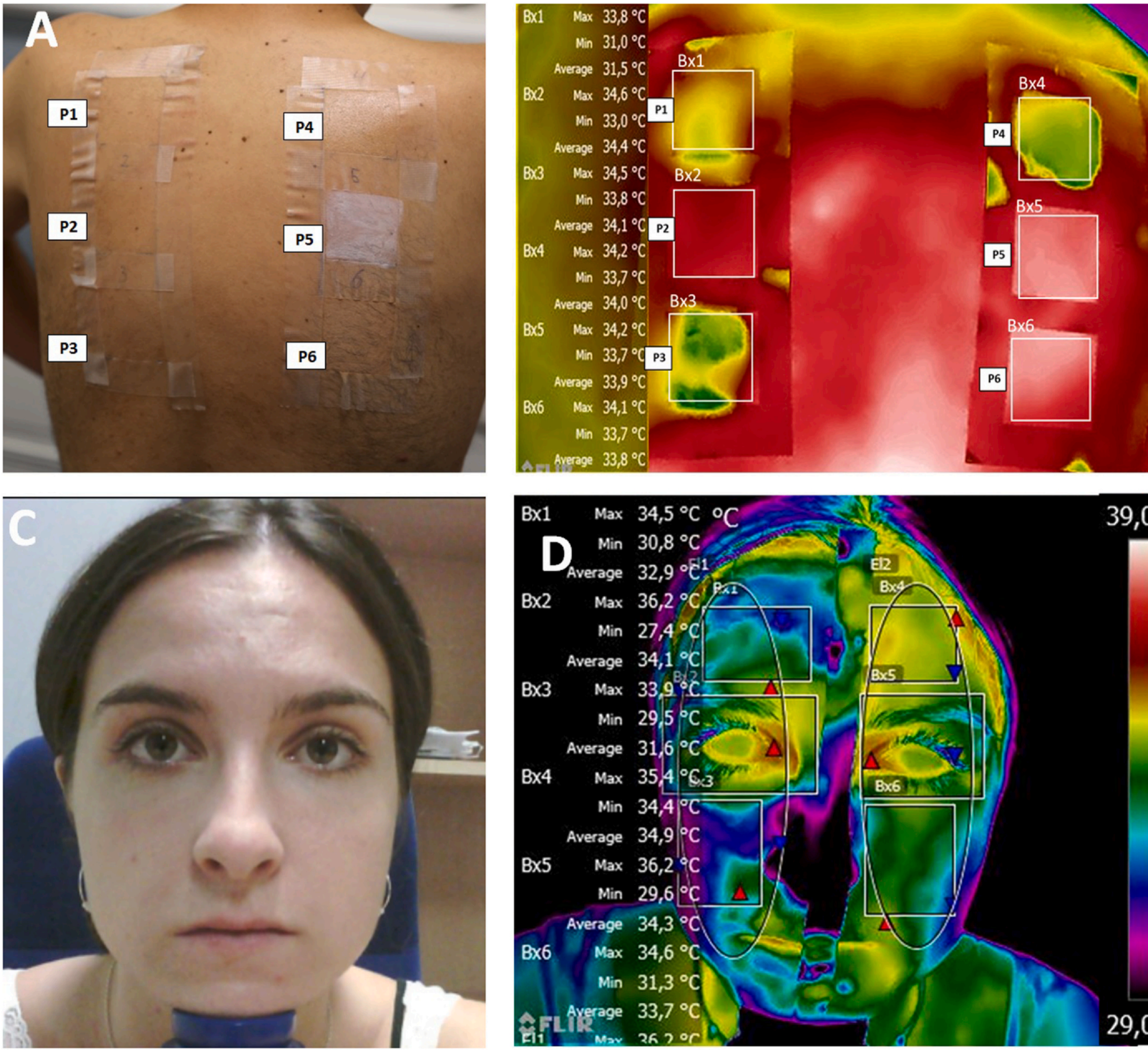

Fig. 1. Study on the back. (A) An example of the normal photo image of the back of a volunteer after application of all the topical substances (observe P5, a 100% mineral sunscreen with white color and P6 with color make up). (B) Example of the thermographic image of the same volunteer at 4 minutes after the application of the first product (observe temperature decrease in productos 1-3). From thermal images, maximal, minimal, and average temperatures can be measured in all product application areas independently. P1—hydroalcoholic gel, P2—ISIDN transparent sunscreen, P3—Heliocare 360 water gel sunscreen, P4—Heliocare 360 color sunscreen, P5—AVENE 100% mineral sunscreen and P6—color make-up. (C) Standard photo image of the face. (D) Example of the thermal image 1 minute after the application of thermographic image processing after application of topical formulas on the right half face. Four subareas were distinguished: (1) forehead, (2), eye, (3), cheek, and (4), the entire right half-face. The left half-face was used as the untreated control.

a drop of −2.18°C just 1 minute after its application, being the most drastic temperature change of all the cosmetics studied. Similarly, although less marked, temperature drops were obtained for helicocare 360 water gel (no color) (P2), Heliocare 360 color (P3), and Avene 50 (no color) (P6) of −1.69°C, −1.62°C, and −1.10°C respectively. The same behavior was obtained for all products, with a skin temperature drop after 1-2 minutes of application and the progressive recovery was observed to initial basal values after 9 minutes. After that, the values remained constant over time.

In contrast, the application of ISDIN Clear (P4) and Color Make-up (P5) resulted in the lowest thermal decrease patterns of the products tested, with an average decrease of −0.85°C and −0.42°C respectively, followed by a rapid recovery phase.

Thermal analysis of face

Figure 4 shows as an example of the thermal evolution on the right half-face (compared to the nontreated left half-face) of a volunteer after the application of the hydroalcoholic gel. As specified in the material and methods section, for each product analyzed results were the average values for 5 different volunteers (mean data of the facial temperatures after hydroalcoholic gel were applied are shown). The face was divided into 2 halves, the right half-face on which the product was applied and the left half-face on which the product was not applied (untreated control). Figure 5A-D shows the mean values of temperature changes at each time interval for each of the 4 types of products tested. Each figure shows the values in 1 of

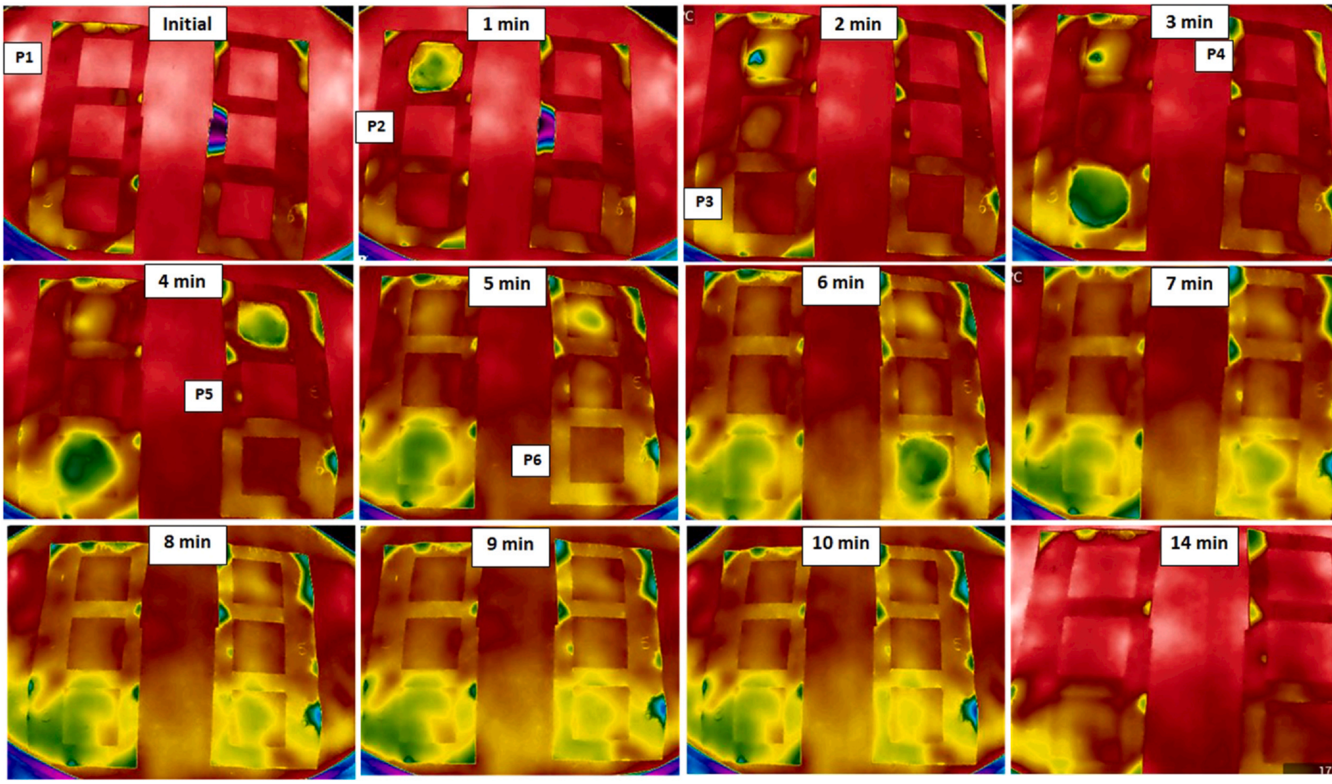

Fig. 2. Evolution of skin temperature after application of different galenic formulations. Each image is taken at 1 minute interval. P1 was applied at an initial time and P2 was applied after 1 minute and sequentially the rest of the products. In the image, each product is marked just at the time when it was applied in the image sequence. So thermal evolution after each product application could be followed at 1 minute interval until 15 minutes of exposure for all products (only the first 14 minutes are represented. P1—hydroalcoholic gel, P2—ISIDN transparent sunscreen, P3—Heliocare 360 water gel sunscreen, P4—Heliocare 360 color sunscreen, P5—AVENE 100% mineral sunscreen, and P6—color make-up.

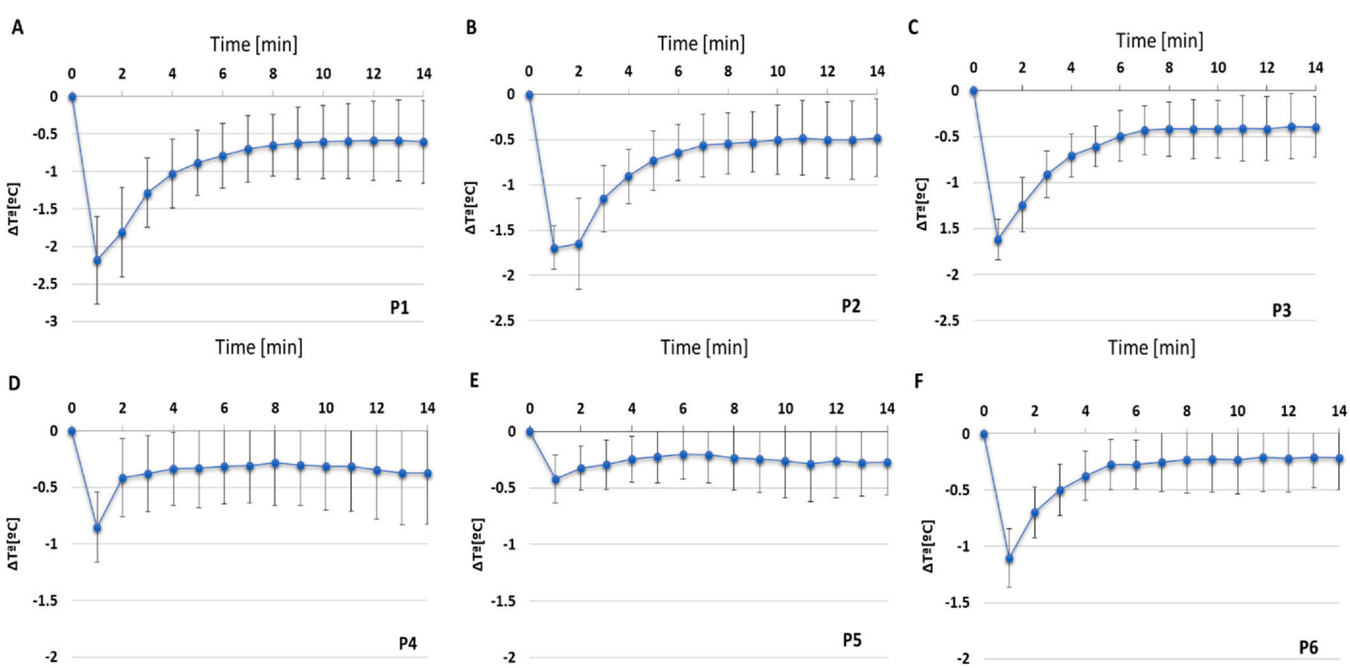

Fig. 3. (A-F) Time evolution, within 1 minute interval of the mean temperature ± SD n = 20) of the areas corresponding to each of the topical formulas applied the back of the volunteers. Values represent the temperature decrease (°C) with respect to the initial temperature (0 = baseline) just before the application of each product. P1—hydroalcoholic gel, P2—ISIDN transparent sunscreen, P3—Heliocare 360 water gel sunscreen, P4—Heliocare 360 color sunscreen, P5–AVENE 100% mineral sunscreen and P6—color make-up.

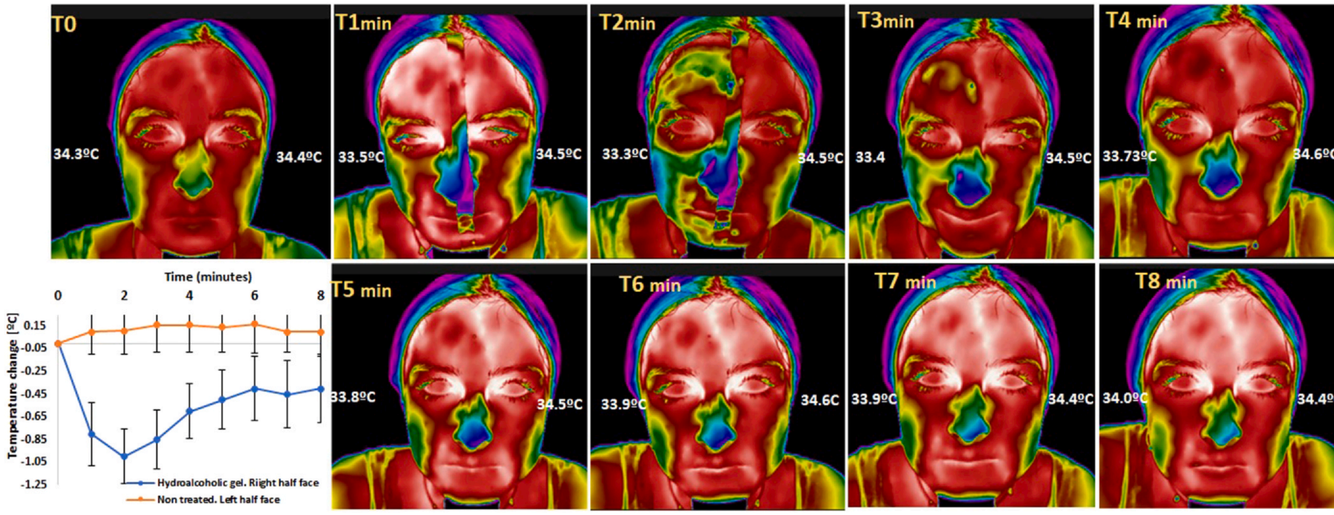

Fig. 4. Example of thermographic images of the face of a volunteer at different time intervals (1 minute) after the application of hydroalcoholic gel. Each volunteer applied 1 product on the right half of the face and the thermal evolution and images were taken at 1 minute intervals until 12 minutes of exposure (images are shown until min 8 because no changes were later observed). As example, a figure with the comparison of the mean temperatures ± SD (n = 5) of the right treated forehead compared to the nontreated left half is shown.

the 3 zones of each half-face analyzed and the average of the right half-face.

When evaluating the thermographic records of the forehead area of the volunteers, it could be observed that the organic sunscreen formula (Heliocare 360 water gel) showed an average decrease of up to −2.08°C, with a nonsignificant different temperature drop as observed by the hydroalcoholic gel (−1.72°C, $P < .05$). In case of the mineral sunscreen (Avene 50) and the pigmented make-up results were similar as in the backtest, where temperature decrease was much lower than the other water gel and hydroalcoholic formulas (−1.02°C, and −0.38°C respectively) (Fig 5A).

The records for the eye region were not analyzed since no product was applied in this region, and minimal variation from the baseline records was observed (Fig 5B).

The graph for the cheek region showed a decrease in the average of −2.02°C for the organic sunscreen (Fig 5C). Likewise, the average records for the rest of the other products are less significant with the average for hydroalcoholic gel at −0.98°C, mineral sunscreen 50 at −0.98°C, and pigmented makeup at −0.68°C.

Finally, it was observed that the average of the thermographic recordings on the right hemiface is representative of the areas segmented above. Similar to what was observed on the back, with all the products there was a rapid temperature drop immediately after application, followed by a gradual and sustained thermal recovery. In the corresponding graph of the average temperature decrease values for the right half-face, a decrease in the average of −1.5°C was observed in the case of organic sunscreen (Fig 5D) followed by the hydroalcoholic gel being −0.90°C, mineral sunscreen −0.6°C and pigmented makeup −0.45°C.

In relation to the left side of the face not treated with any of the products studied (Fig 5E-H), no significant differences were observed in the thermal patterns, with temperature oscillations of the different areas of the face below 0.5°C ($P < .05$), which indicated no changes in the thermographic images repeated over time.

Changes on thermal responses related to basal temperature

One of the hypotheses of this study was that a person currently coursing with an episode of thermal body increase could decrease the skin temperature significantly only with the application of galenic formulations. In order to check if the baseline temperature of a person could affect the temperature drop after application of a topical galenic formulation we performed regression analysis of the decrease of temperature related to that basal temperature. The Figure 6 shows the regression analysis of temperature decrease with respect to the basal temperature for the different topical products. The volunteers showed back skin baseline temperatures from around 32°C up to 34.7°C. It was found a significant dependence on the decrease of temperature with respect to the baseline temperature. It was found a significant dependence of temperature drop with respect to the basal temperature for 5 of the 6 galenic formulations assayed on the back of the volunteers following a linear regression model with significant ($P < .05$) correlation coefficients between 0.44 and 0.56. In the case of the products as hydroalcoholic gel (Fig 6A) as well as water-based organic sunscreen formulas (products 2 and 3, Fig. 6B, C) the volunteers with higher basal temperatures showed decreases over 2°C. In the case of hydroalcoholic gel, the temperature drop was found around 3°C in volunteers with the basal temperature of the back over 34.5°C. Only color makeup application showed no correlation between basal temperature and temperature decrease ($P > .05$) (Fig 6F).

In the case of the face study, in spite of less samples per galenic formulation assayed (n = 2) the regression lines showed better correlation coefficients between temperature decreases and the basal temperature of the volunteer hemiface (R2 ranging from 0.66 to 0.75). Again the water-based sunscreen organic filter formulas showed higher temperature drops (around 2°C) in the face of volunteers with basal temperatures over 35°C.

DISCUSSION

An experimental protocol allows, by means of the use of thermographic cameras, an analysis of the thermal dynamics of the skin in healthy people after the topical application of galenic formulas, both on the back and on the face. Samples were selected to comparatively analyze a group of formulas currently used as a normal topical application for skin with different finalities, such as hydroalcoholic gel for disinfection, which is widespread used as one of the preventive measures against the spread of COVID-19.[21] In addition, photoprotection products were selected as sunscreens based on both organic filters, which are capable of absorbing ultraviolet (UV) radiation and

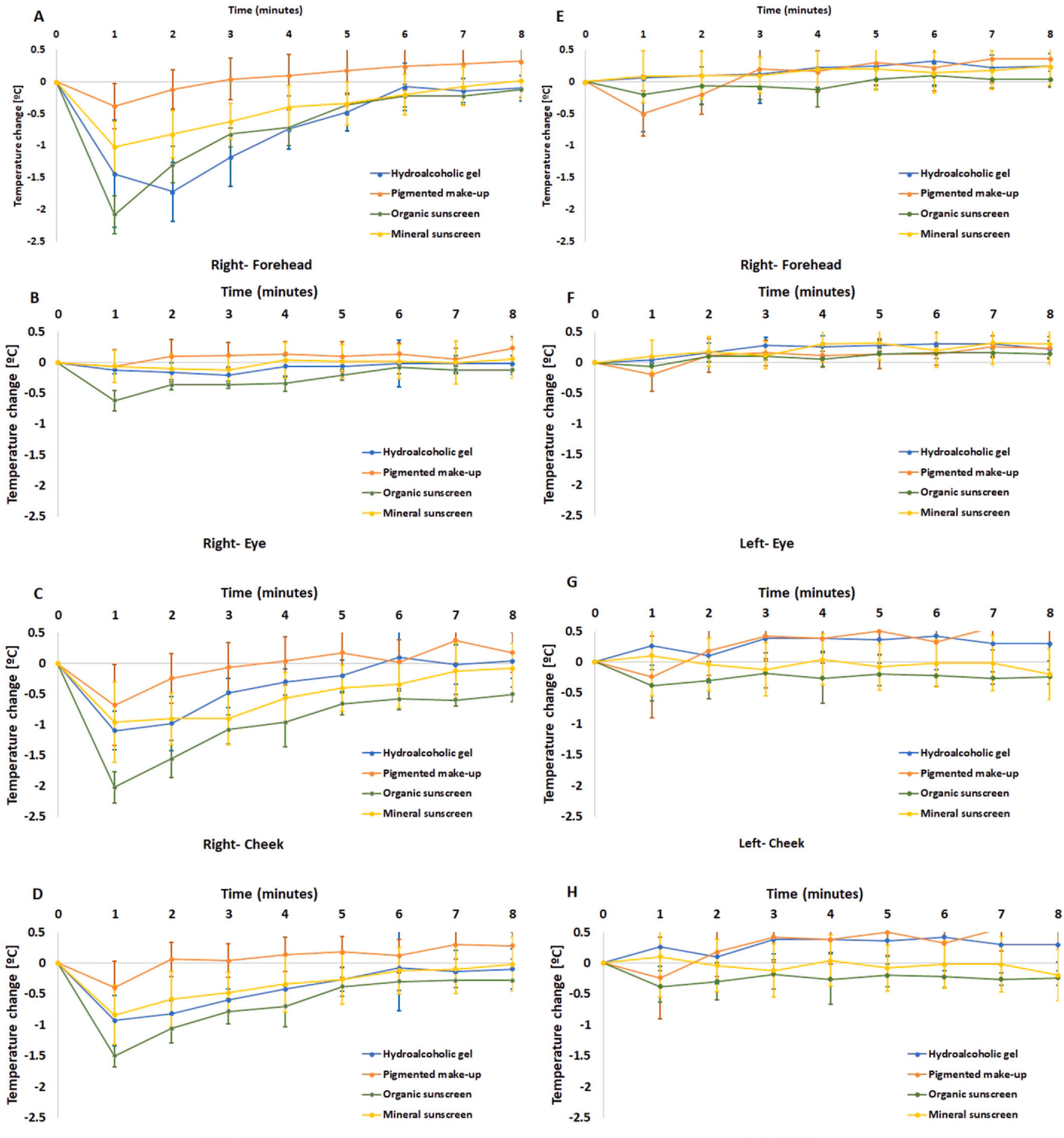

Fig. 5. Average values of measurements ± SD for all volunteers per product at 1 minute time intervals and for each of the right half-face areas treated. Four subareas were distinguished. (A, E) Forehead, (B, F). Eye, (C, G) Cheek, and (D, H) The entire half-face. P1—hydroalcoholic gel, P2—Heliocare 360 water gel sunscreen, P3—AVENE 100% mineral sunscreen, and P4—color make-up. (E-H) Average values of the measurements for all volunteers at 1-minute time intervals and for each of the untreated left half-face areas.

transforming it into heat, and mineral filters, which are able to reflect and scatter solar radiation, such as titanium dioxide, zinc oxide, mica, and talc.[22] In addition, a make-up base rich in iron oxides was used, which together with the other mineral sunscreens has light-reflecting characteristics not only in the UV spectrum but also in the visible and infrared spectrum, which could lead to a possible alteration of the thermographic images.[23,24] Sunscreens are the topical formulas most commonly used by the general population, particularly in our area in Southern Europe, at the Costa del Sol, which due to its environmental conditions attracts millions of tourists every year who are forced to apply sunscreen products to avoid the harmful effects of UV solar radiation on the skin.

As we demonstrated, the application of cosmetic products significantly alters the thermal response of the skin in a short period of

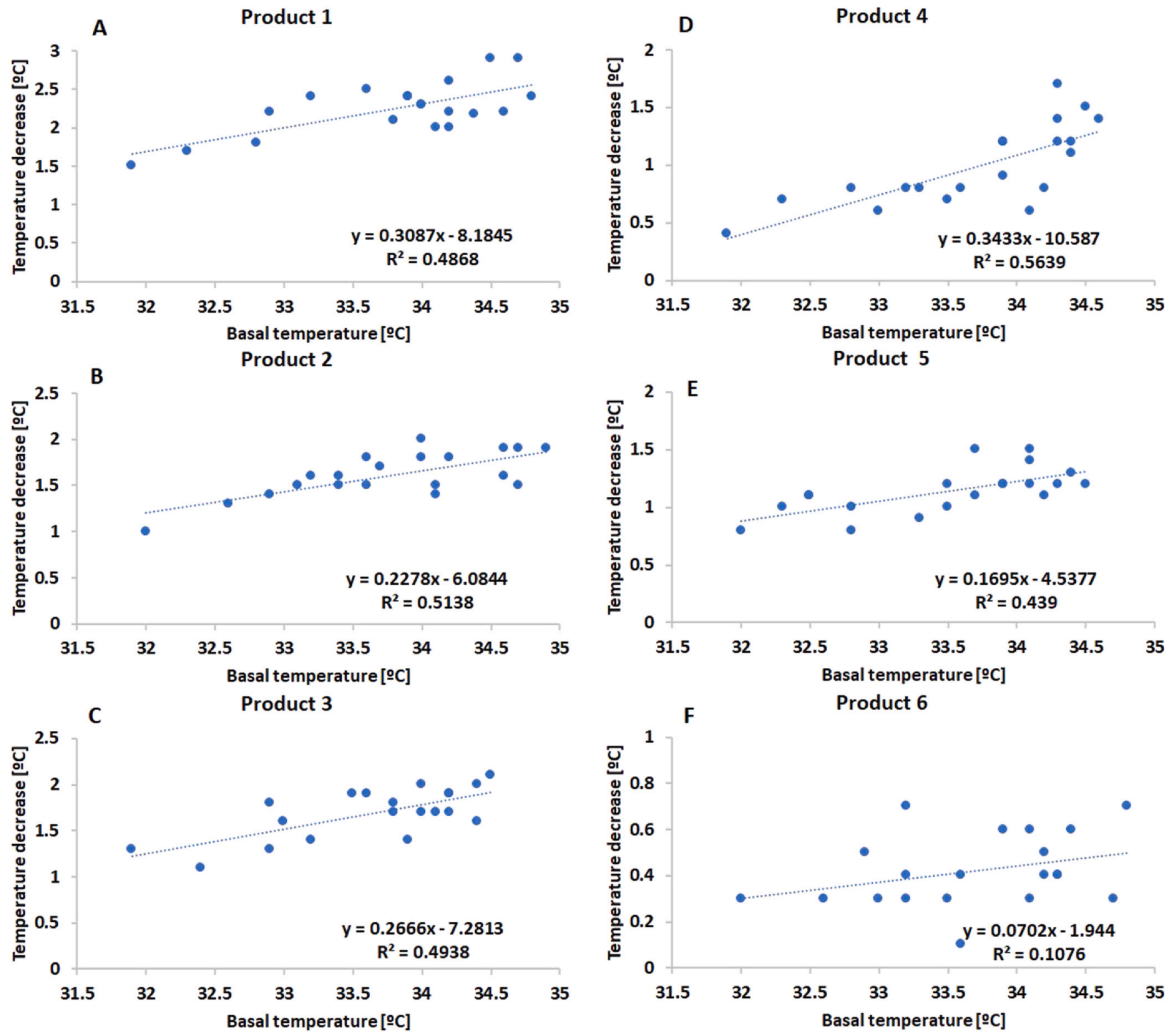

Fig. 6. Linear regression analysis of the decrease of temperature with respect to the basal temperature in all volunteers (n = 20) after the application of the different galenic formulations on the back. Correlation coeficients for each are also shown. A) P1—hydroalcoholic gel, B) P2—ISIDN transparent sunscreen, C) P3—Heliocare 360 water gel sunscreen, D) P4—Heliocare 360 color sunscreen, E) P5—AVENE 100% mineral sunscreen and F) P6—color make-up.

time. Depending on the product used, very rapid thermal decreases were observed at different levels, with the hydroalcoholic gel showing the lowest average decrease among all the formulas in the back application followed water gel sunscreens formulas.

Taking into account that the hydroalcoholic gel is mainly composed of 70% alcohol, which is volatile in nature; it evaporates quickly, producing rapid temperature drops on the surface of the skin, as shown by thermographic measurements. The early thermal recovery which, although occurring at intervals of several minutes, could be sufficient to lead to measurement errors at control points such as airports, ports, or land borders, serving as a pathway for the spread of infectious diseases among populations such as the current COVID-19.

In relation to the sunscreen formulations, water-rich gel emulsion-based formulations such as Heliocare 360 water gel and Heliocare 360 with color pigments showed the most significant decreases on the back. However, we cannot attribute this effect merely to the presence of mineral and/or chemical filters, even though they are present in relatively higher concentrations than the other components of each product according to the labeling that complies with the international nomenclature of cosmetic ingredients standard.[19] In the case of more oily water-free sunscreen formulas as such as ISDIN transparent with oil-based organic filters and Avene 50, with 100% mineral filters in a cream base, did not produce significant decreases. The same was observed for the iron oxide-based pigment-rich make-up base, which did not significantly affect the thermal response. Therefore, the samples tested with high % ethanol and water or water-rich formulas, due to their potential rapid evaporation, are the formulas to which the greatest thermal drop of the skin in a short period of time can be attributed. It could be also possible that the potential thermal changes in skin could be due to the presence of other substances in the excipients (extracts of *Polypodium leucotomos*, vitamins A, E, C, quercetin, aloe vera, etc.) that could affect the possible thermal response of the skin or alteration of the thermographic images, although the phenomenon of

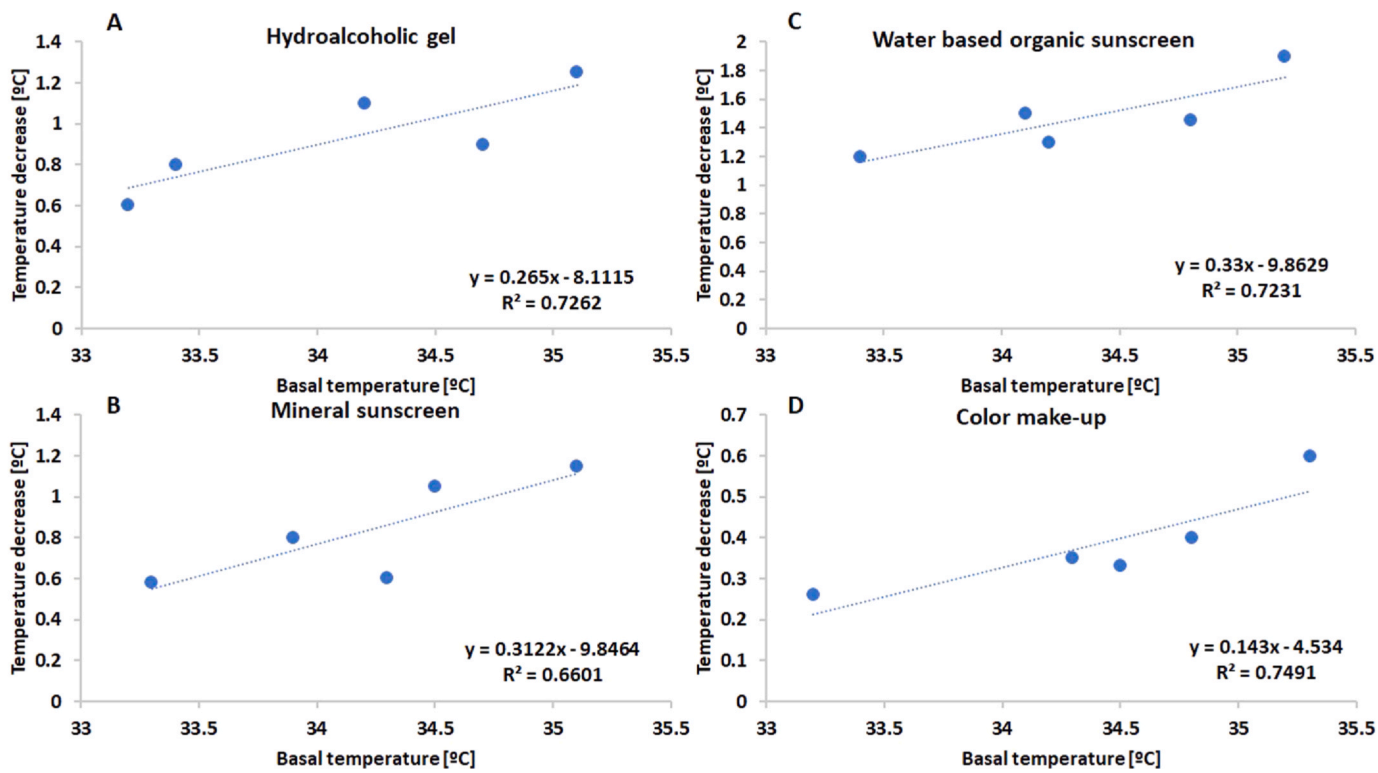

Fig. 7. Linear regression analysis of the decrease of temperature with respect to the mean basal temperature in all volunteers (n = 5) after the application of the different galenic formulations on the right half face. Correlation coefficients for each are also shown. A) P1—hydroalcoholic gel, B) P2—Heliocare 360 water gel sunscreen, C) P3—AVENE 100% mineral sunscreen, and D) P4—color make-up.

evaporation with the consequent loss of heat seems to be the most important phenomenon behind the application of topical substances.

On the other hand, the phenomenon of alterations in the reflection of light due to the presence of substances with this potential as the presence of mineral substances has no effect on the thermographic measurements.

On the face, the results were similar to those observed for the different products on the back, despite the fact that the volunteers were instructed to apply the product under conditions of normal use, without specifying the quantity as in the back tests. The observed decrease in the averages with respect to the basal record also suggests that some of them were able to alter the facial temperature just after the application, after which a generalized thermal recovery was observed. It could be observed that the formula given in the product "Heliocare 360 Water Gel" together with the hydroalcoholic gel were the 2 types of formulas most effective in lowering the temperature. On the contrary, both the 100% mineral sunscreen and the make-up rich in mineral pigments were the least effective. The higher thermal drop effect of water gel sunscreen in the face could be due that according to the sunscreens application of 2 mg/cm^2 on the skin, the total quantity of this compound was higher than the use of hydroalcoholic gel, so, the evaporation effect was higher in water gel sunscreen.

When evaluating the averages of the thermographic recordings according to the different areas of the face, it became evident that, among the different anatomical regions, the forehead is the place where the lowest averages were recorded for all the formulas, except for the "Make-up" which recorded a slightly higher average decrease on the cheek than on the forehead, perhaps because the product was applied unevenly in the different regions and/or in very variable and low quantities, mainly due to its type of galenic formula, which is difficult to apply and high color remains in face. It was also observable that the hydroalcoholic gel showed a faster thermal recovery in the cheekbone and cheek compared to the forehead, and this could be due, in part, to the greater blood vascularization in the former area than in the latter. However, the eye area showed minimal difference from the baseline recording, and this was due to the fact, that after applying the product to the other areas of the face it was difficult to keep the edges of the eye area free of product.

It should be noted in this part of our study of thermographic variability in the face that, due to anatomical (facial) variations between different volunteers in the same group, in addition, the fact that the same amount of product was not applied to all volunteers leads to greater variability of data, or in other words, less precision, although with similar results to the back.

The results obtained in our study are of great importance due to the increased use of thermography in the field of public health in the wake of the COVID-19 pandemic.[11,15,25] In the case of the SARS epidemic in 2003, the World Health Organization recommended detecting at least 1°C above normal temperature[26]; which has served as an example for patient screening in the case of the current COVID-19.[10,27]. We have shown that with the use of water-based sunscreens as well as with the use of hydroalcoholic gel the skin basal temperature of a person can be decreased over 2°C. According to the regression line models made from data from all volunteers of the study (Fig. 6 and 7) the decrease of temperature is higher when the basal temperature of the skin increases. Thus, in the case of persons that currently courses with fever symptoms could decrease skin temperature easily just in the course of 1-2 minutes after topical compound application making more difficult the thermographic screening in some situations.

Finally, it is important to emphasize the importance of measuring fever correctly by thermography in accordance with existing standards and protocols; this can only be achieved if we have thermal cameras with optimum resolution and the appropriate software to meet the different needs, as otherwise, the drop in temperature observed in our study following the use of cosmetic products could alter the thermal reading, thus posing a danger to public health.

CONCLUSIONS

In summary, this is the first work related to alterations of the thermal image as a consequence of the application of topical cosmetic formulas as well as the widespread use of hydroalcoholic gel in the context of the COVID-19 pandemic. Both the back and the face decreased fast skin temperature from the first minute after application, and then recovered, on average, after 10 minutes. This finding may alter the febrile syndrome screening of people in transit areas, such as airports or other high-people movement situations. Situations where measurements have to be instantaneous, automatized, and massive, could lead to mismatch readings for the detection of human symptoms caused after SARS-CoV 2 infection and so making difficult to control the current global pandemic.

CONSENT TO PUBLISH

The authors affirm that human research participants provided informed consent for the publication of the image in Figures 1C and 4A.

References

1. Diffey B. Natural and simulated solar radiation. *Curr Probl Dermatol.* 2021;55:44–52.
2. Law J, Morris DE, Budge H, Symonds ME. Infrared thermography. *Handb Exp Pharmacol.* 2019;251:259–282.
3. Hildebrandt C, Raschner C, Ammer K. An overview of recent application of medical infrared thermography in sports medicine in Austria. *Sensors.* 2010;10:4700–4715.
4. Lahiri BB, Bagavathiappan S, Jayakumar T, Philip J. Medical applications of infrared thermography: a review. *Infrared Phys Technol.* 2012;55:221–235.
5. Tattersall GJ. Infrared thermography: a non-invasive window into thermal physiology. *Comp Biochem Physiol A Mol Integr Physiol.* 2016;202:78–98.
6. Stekeete J. Spectral emissivity of the skin and pericardium. *Phys Med Biol.* 1973;18:686–694.
7. Jones BF. A reappraisal of the use infrared thermal image analysis in medicine. *IEEE Trans Med Imaging.* 1998;17:1019–1027.
8. Watmought DJ, Flowler PW, Oliver R. The thermal scanning of a curved isothermal surface. *Phys Med Biol.* 1970;15:1–8.
9. Bagavathiappan S, Jayakumar T, Philip J. Medical applications of infrared thermography: a review. *Infrared Phys Technol.* 2012;55:221–235.
10. Politi S, Aloisi Jr A, Bartoli V, et al. Infrared thermography images acquisition for a technical perspective in screening and diagnostic processes: protocol standardized acquisition. *Cureus.* 2021;27:e19931.
11. Ng EYK, Kaw GJ, Chang WM. Analysis of IR thermal imager for mass blind fever screening. *Microvasc Res.* 2004;68:104–109.
12. Ng EYK. Is thermal scanner losing its bite in mass screening of fever due to SARS? *Med Phys.* 2005;32:93–97.
13. Chiang MF, Lin PW, Lin LF, et al. Mass screening of suspected febrile patients with remote-sensing infrared thermography: alarm temperature and optimal distance. *J Formos Med Assoc.* 2008;107:937–944.
14. Ogawa T, Tsukuda Y, Suzuki Y, et al. Utility of thermal image scanning in screening for febrile patients in cold climates. *J Orthop Sci.* 2021;3:S0949–S2658.
15. Khaksari K, Nguyen T, Hill B, et al. Review of the efficacy of infrared thermography for screening infectious diseases with applications to COVID-19. *J Med Imaging.* 2021;8:010901.
16. Martinez-Jimenez MA, Loza-Gonzalez VM, Kolosovas-Machuca ES, et al. Diagnostic accuracy of infrared thermal imaging for detecting COVID-19 infection in minimally symptomatic patients. *Eur J Clin Investig.* 2021;51:e13474.
17. Brzezinski RY, Rabin N, Lewis N, et al. Automated processing of thermal imaging to detect COVID-19. *Sci Rep.* 2021;11:17489.
18. Peddinti B, Shaikh, A K. Framework for real-time detection and identification of possible patients of COVID-19 at public places. *Biomed Signal Process Control.* 2021;68:102605.
19. Regulation (EC), No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products.
20. Schober P, Boer C, Schwartencluded LA. Correlation coefficients: appropriate use and interpretation. *Anesth Analg.* 2018;126:1763–1768.
21. Seyed Hosseini E, Riahi Kashani N, Nikzad H, et al. The novel coronavirus Disease-2019 (COVID-19): mechanism of action, detection and recent therapeutic strategies. *Virology.* 2020;551:1–9.
22. Krutmann J, Schalka S, Watson REB, Wei L, Morita A. Daily photoprotection to prevent photoaging. *Photodermatol Photoimmunol Photomed.* 2021;37:482–489.
23. Lyons AB, Trullas C, Kohli I, Hamzavi IH, Lim HW. Photoprotection beyond ultraviolet radiation: a review of tinted sunscreens. *J Am Acad Dermatol.* 2021;84:1393–1397.
24. Serpone N. Sunscreens and their usefulness: have we made any progress in the last two decades. *Photochem Photobiol Sci.* 2021;20:189–244.
25. Viswanathan M, Kahwati L, Jahn B, et al. Universal screening for SARS-CoV-2 infection: a rapid review. *Cochrane Database Syst Rev.* 2020;15:CD013718.
26. Chan LS, Cheung GT, Lauder IJ, Kumana CR, Lauder IJ. Screening for fever by remote-sensing infrared thermographic camera. *J Travel Med.* 2004;11:273–279.
27. Perpetuini D, Filippini C, Cardone D, Merla A. An overview of thermal infrared imaging-based screenings during pandemic emergencies. *Int J Environ Res Public Health.* 2021;18:3286–3298.