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The mental and subjective skin: Emotion, empathy, feelings and thermography

E. Salazar-López [*,1,2], E. Domínguez [1], V. Juárez Ramos [1], J. de la Fuente [1], A. Meins [3], O. Iborra [1], G. Gálvez [4], M.A. Rodríguez-Artacho [5], E. Gómez-Milán [1]

Centro de Investigación Mente Cerebro y Comportamiento (CIMCYC), University of Granada, Spain

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ABSTRACT

We applied thermography to investigate the cognitive neuropsychology of emotions, using it as a somatic marker of subjective experience during emotional tasks. We obtained results that showed significant correlations between changes in facial temperature and mental set. The main result was the change in the temperature of the nose, which tended to decrease with negative valence stimuli but to increase with positive emotions and arousal patterns. However, temperature change was identified not only in the nose, but also in the forehead, the oro-facial area, the cheeks and in the face taken as a whole. Nevertheless, thermic facial changes, mostly nasal temperature changes, correlated positively with participants' empathy scores and their performance. We found that temperature changes in the face may reveal maps of bodily sensations associated with different emotions and feelings like love.

1. Introduction

Back in 1890, William James wrote, "Brain-activity seems accompanied by a local disengagement of heat (...). He [Dr. S. Lombard in 1867] noted the changes in delicate thermometers and electric piles placed against the scalp in human beings, and found that any intellectual effort, such as computing, composing, reciting poetry silently or aloud, and specially that emotional excitement such as an anger fit, caused a general rise of temperature" (pp. 99–100). Since then, thermography as a technique has increasingly been employed in the field of psychology in order to study psychological processes.

One of the advantages of thermography is the reduction in noise often collected in physiological measurements (Agnew & Wise, 2008). It is rather simple to differentiate between physiological measurements of various parts of the subject's body like the nose, the forehead or the cheeks, obtaining a reasonably low level of data contamination (Or & Duffy, 2007). However, initial thermographic research concentrated on mental workload. Studies by Genno et al. (1997) used it to measure mental workload in relation to the evaluation of fatigue. They conducted experiments in which the temperature of the skin

* Corresponding author.
E-mail address: elvisalazar@gmail.com (E. Salazar-López).
[1] Address: Department of Experimental Psychology, University of Granada, Faculty of Psychology, Campus of Cartuja s/n, 18071 Granada, Spain.
[2] Address: Chair of Human Movement Science, Technique University of Munich, Georg Brauchle Ring 62, M302, 80992 Munich, Germany.
[3] Address: California School of Professional Psychology, Alliant International University, Beach Street 1, 94133 San Francisco, United States.
[4] Address: Departamento de Psicología, Universidad de la Frontera, C/Francisco Salazar 1145, 4811230 Temuco, Chile.
[5] Address: Department of Personality, Assessment and Psychological Treatment, University of Granada, Faculty of Psychology, C/Campus de Cartuja s/n, 18071 Granada, Spain.

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was shown to have a great potential as a physiological measure, because when using a thermographic camera no physical contact with the subject is needed. The autonomic nervous system's response to stress causes a change in the temperature of the skin, which the experimenters measure in the nose, a part of the body that, despite experiencing little movement, can undergo variations in temperature under stressful conditions. Their results reveal a decrease in nasal temperature during stressful situations due to vasoconstriction, which leads to a reduction of blood flow to the peripheral capillaries of the nose, causing the decrease in temperature (Genno et al., 1997; Veltman & Vos, 2005). However, the temperature of the forehead is one of the most stable temperatures in the body (Stoll, 1964), so Genno et al. (1997) used it as a reference area. Veltman and Vos (2005) remind us that the change in nasal temperature is the important measurement, and not the absolute value of the temperature (considering that mental workload may not be the only factor that affects nose temperature). Their methodology is to use thermographic cameras and determine which Region of Interest (ROI) should be studied. This paradigm confirmed the equivalency of the temperatures of the forehead and the nose in rest condition and the change in temperature of the nose in all of the conditions in which mental workload was manipulated (Or & Duffy, 2007).

Few studies apply thermography to the study of emotions. Pavlidis, Eberhardt, and Levine (2002) have used infrared cameras to measure participants' facial temperatures, based on the idea that facial temperature changes in various regions of the face correlate with emotional experience. In particular, they have studied the emotions of deceit and anxiety and found evidence that facial temperature changes can indeed predict both. However, the results of thermographic studies are sometimes inconclusive. Briese and Cabanac (1991) found that stress levels correlate with increased blood flow in the frontal vessels of the forehead. Tanaka, Ide, and Nagashima (1999) and Nagumo, Zenju, Nozawa, Ide, and Tanaka (2002) obtained correlations between arousal level and nasal skin temperature. Zenju, Nozawa, Tanaka, and Ide (2004) and Zenju, Nagumo, Nozawa, Tanaka, and Ide (2002) found that nasal skin temperature rises when shifting to pleasant mental states and fall when shifting to unpleasant mental states. Similarly, Nakayama, Goto, Kuraoka, and Nakamura (2005) and Kuraoka and Nakamura (2011) obtained decreased nasal temperature in negative emotional states, but Nakanishi and Imai-Matsumura (2008) observed facial skin temperature decrements also during joyful expressions in the nose. Robinson et al. (2012) found that warming of the brow, near the corrugator muscle, and the cheek, near the zygomatic major muscle, are related to less positive feelings but that warming in the eye area, near the orbicularis oculi, is related to positive self-sentiments. The correlations between facial thermal changes and other brain or physiological measures are clearly significant during experimental tasks but also for ecological tasks such as driving, as has been demonstrated by Sheba, Elara, Lerín, Martínez-García, and Torres-Córdoba (2012). Poppendieck, Ruff, Fernández, and Hoffman (2009), Jarlier et al. (2011), and Jenkins, Brown, and Rutterford (2009) employed EEG, EMG, GSR, and heart rate, in their works to demonstrate these correlations. Dimberg, Andréasson, and Thunberg (2011) argued that emotional empathy is linked to facial reaction to the facial expressions of others. In other words, people with high empathy are more facially reactive when exposed to pictures of angry and happy facial expressions. Facial EMG was measured in the corrugator and the zygomatic muscles, derived from the above-cited research which examines the warming of the brow and cheek with regard to facial thermal changes. However, researchers such as Khan, Ward, and Ingleby (2006) and Khan, Ward, and Ingleby (2009) have opened new lines of research in this area: the relationship between thermographic changes and feelings. Their experiments show variations in the intensity of the temperature in subjects that express positive and negative affective states, particularly in states of happiness and sadness.

In short, thermography can be considered a biometric measurement of human emotions, but arousal, valence, Ekman (1970) basic emotional states, stress, empathy or feelings, including complex emotions such as love or happiness, are not differentiated in previous research. The characteristics of the populations employed (adults, infants, elderly or animals), the ecological or laboratory context and the different tests and stimuli employed yield contradictory results, such as the thermal increments or decrements associated with empathy or positive emotions.

The main goal of the present study is to ascertain whether facial thermograms can be used as a valid and reliable somatic indicator of emotional parameters. Specifically, we want to determine if there is a relation between changes in temperature of the face and valence, arousal, empathy and subjective feelings. The principal aim of our research is to validate the use of thermography as an effective experimental paradigm to study emotions and to discover the somatic indicators of subjective feelings.

We approach these questions via three experiments: 1. The thermal effect of valence (positive and negative) and arousal (high or low) of IAPS images; 2. The thermal effect of empathy; 3. The thermal imprint of subjective experiences felt in the body and face, following Nummenmaa, Glerean, Hari, and Hietanen (2014): the case of love.

2. Experiment 1. The thermal effect of valence (positive and negative) and arousal (high or low) of IAPS images

According to the emotions theory developed by Lang (1995) see also (Lang, Bradley, & Cuthbert, 2005; Vila et al., 2001), valence and arousal are the key factors in this field. In Experiment 1.a we study whether the positive or negative valence of the IAPS images produces different thermal changes in the face. Previous studies suggest that positive images increase facial temperature while negative images lower it. In Experiment 1.b we focus on the thermal effect of high arousal, hypothesizing that the temperature of the nose and/or forehead correlates with the level of arousal.

2.1. Method

2.1.1. Participants

This study uses data derived from university students, 60 women and 60 men, between 24 and 47 years of age, ($M = 34.2$, $SD = 6.9$), who participated in a study of "Feelings" conducted in the Department of Experimental Psychology at the University of Granada during the first semester of 2013. Eighty of them (half of whom were women) participated in Experiment 1.a and the rest (40, half of whom were women) in Experiment 1.b. All participants signed a consent form and were informed of the method. We also obtained ethical permission from our research group (SEJ-497) in CIMCYC for this research. Vulnerability to psychosis was assessed with the Community Assessment of Psychic Experience, CAPE (Konings, Bak, Hanssen, Van Os, & Krabbendam, 2006). The inclusion criteria for the participants was a total score within the normal range (the score for non-clinical populations were found to range from 1.4 to 1.8). Premorbid intelligence was determined by the Test de acentuación de palabras TAP-30 (González Montalvo, 1991). All participants reported an absence of cerebral damage and there was no clinical evidence of drug abuse during the course of the study. Additionally, no participants reported a mental disorder.

2.1.2. Stimuli

The stimuli employed in our study were pictures from the International Affective Picture System (IAPS) by Lang et al. (2005), a validated instrument frequently used in researching emotion in English as well as Spanish (Moltó et al., 1999). The IAPS used in this experiment were re-evaluated in valence (0–9 points) and arousal (0–9 points), employing the Self-Assessment Manikin (SAM) by Bradley and Lang (1994) in Spanish (Vila et al., 2001).

The current version of IAPS consists of 832 color images, available in digital format, belonging to various semantic categories: portraits, nudes and erotica, animals, household objects, dead and mutilated bodies, sport and fitness, etc. We employed four groups of images (sets of 30 images) following Moltó et al. (1999): *Set 1*. Positive images with low arousal: SAM score greater than or equal to six for valence and less than or equal to four for arousal – for example, pictures of landscapes, happy families, good looking children or flowers; *Set 2*. Negative images with low arousal: SAM score less than five for both dimensions – for example, pictures of sad faces, elderly people, insects or cockroaches, and some "ugly" nudes. In the Spanish version of IAPS, it is quite difficult to find negative images with low arousal, so we considered *Set 2b* our neutral condition; it contains pictures neutral in valence and arousal, which means images with five points in both dimensions, for example, neutral faces or home objects like cups, hammers and chairs. *Set 3* contains positive images with high arousal: SAM score greater than or equal to six in both dimensions – for example pictures of nudes, romantic love, sporting activities, etc. *Set 4* includes negative images with high arousal: SAM score less than or equal to four for valence but higher than six for arousal – for example pictures of mutilated bodies, dead people, violent actions, etc. (see Table 1).

2.1.3. Equipment

The ThermoVision A320G Researcher Infrared Camera, which has a potential sensitivity of 0.07–30 °C of difference between successive readings, was used. The camera was placed on a tripod 110 cm above the floor and 60 cm from the subjects. The height was adjusted to capture the subjects' whole body, only the upper body or only the face, in frontal and lateral views, depending on the ROI required. The camera had automatic focus that was always employed to focus the image recording. The signal was recorded on a laptop with the program Researcher TermaCAMP 2.9 that allows continuous recording at 8 frames per second.

2.1.4. Procedure and setting

The experiment was carried out in a closed room of about 40 m^2, with a changing room next to it. The thermographic camera, the computer and the experimenter were positioned in the middle of the room, facing the subject.

The protocol for measuring with thermographic cameras (Ring & Ammer, 2000) demands specific preparation to obtain proper recordings: the area of skin to be recorded must not be covered with fabric as thermography captures images that reflect the temperature; subjects must be at rest for between 10 and 15 min to adapt to room temperature before recording the temperature of the skin, which must be between 18 and 25 °C ($M = 22$ °C in our case). The humidity also has to be controlled ($M = 50\%$ in our case). According to the procedure, when participants entered the room they were required to remain seated for 10 min on a stool in the changing room adjacent to the studio. After this, the participant entered the studio and received instructions similar to the following: "We are now going to record your face while performing different exercises or tasks (...) Firstly, a static image at rest will be recorded and then we will indicate the nature of the tasks to be performed". Each participant was recorded in the Baseline (BL) shot, which shows an initial thermogram of the whole face and after that

Table 1
Description of the set of IAPS images employed in Experiment 1 regarding arousal and valence.

IASP images set	Low arousal	High arousal
Positive valence	Set 1	Set 3
Negative valence	Set 2	Set 4

Fig. 1. Main ROIs following Mize and Myers (2011). The face of each participant was coded in eight separate regions: forehead (left and right part of forehead), one for each eye, for each cheek, the tip of nose, and the mouth, as shown here. The tool bar shows the color code for each temperature. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

one more time during the task performance and the last one after performing the task. To ensure higher quality in the ROIs, the whole sequence of movements comprising each experiment was recorded with thermography.

The relevant ROIs for this project are the entire forehead, capturing both the left and the right side, and the tip of the nose, the best delimited ROI in previous studies. In addition, three regions were recorded: the eye region (area of the orbital-ocular muscle), the mouth region and the cheeks (see Fig. 1 for an example of ROIs in line with Mize and Myers (2011). To guarantee consistent recording of ROIs, we applied the same polygon size for each facial region in all thermograms for each participant, but adapted to each participant's particular face configuration. All participants were their own control for their ROIs; therefore, all participants were recorded in exactly the same position during all tasks, seated in a stool of variable height, with a chin-rest for facial recordings.

The ThermoVision A320G Researcher Infrared Camera provides different color palettes; the medical one was employed since it provides a clearer view of the changes in temperature, which is better suited to our purposes (see the tool bar in the figures). The criteria employed to determine medical changes in thermography establish that they must be greater than 0.5 °C between "twin" ROIs or identical areas in both sides of the body, to consider it a thermal asymmetry (Chlebicka, Matusiak, Baran, & Szepietowski, 2012). For each ROI, we calculated the mean and standard deviation between twin spatial ROIs, and temporal or sequential registers of individual ROI temperature changes. A statistical analysis was performed using the Student *t-test* and Pearson's correlation coefficient, $p < .05$.

Participants were shown images on a large computer screen and asked to complete self-report emotional measurements after each set of images, which varied in their valence and activity ratings. Each image was presented for 5 s, followed by a black screen for 3 s and a response interval of 15 s for the SAM, in sets of 60 images. During the stimuli presentation, the infrared camera recorded thermal images of the subject's face. Accordingly, we focused on the ROIs described above. The IR software that come with the infrared camera was employed to draw the ROIs: the forehead (*corrugator muscle*), around the mouth (*zygomatic major muscle*), around the eyes (*orbicularis oculi muscles*), the nose and cheeks.

2.1.4.1. Experiment 1.a. The valence was manipulated between groups to avoid sequential effects.[6] Half of the participants, $N = 40$, viewed the positive images, of which 20 participants viewed images with low and high arousal randomly mixed: *Set 1* and *Set 3*; 10 of them viewed only *Set 1* and the remaining 10 only *Set 3*. The other half of the participants, $N = 40$, were shown the negative ones. Twenty participants viewed images with low and high arousal randomly mixed: *Set 2* and Set *4*; 10 participants only viewed *Set 2* and the rest saw only *Set 4*. *Set 2b* or the neutral condition was presented 10 min before the experimental condition to half of the participants and 10 min after to the rest.

[6] The IAPS with neutral arousal and valence are not easy to find; these two dimensions are not completely independent (Mata Martín, 2006) and for that reason the results in previous studies could be sometimes confusing. Considering the temperature a dependent variable, it is not possible to manipulate the independent variables intra subject but between groups, due to the prolonged inertia in the thermic change, also called the prolonged sequential effect. In Experiment 1.a, the positive and negative valence is compared between groups, and arousal cannot be used to explain differences between groups since both are equal regarding arousal; arousal is fixed in the mixed condition: the arousal level for the mixed condition with positive images (*Set1* plus *Set3*) and the arousal level for the mixed condition with negative images (*Set2* plus *Set4*) was similar ($t(39) = 1.15$, $p = .15$). We present also the comparison between groups for positive and negative valence with low arousal or high arousal alone in Tables 1 and 2 in the text.

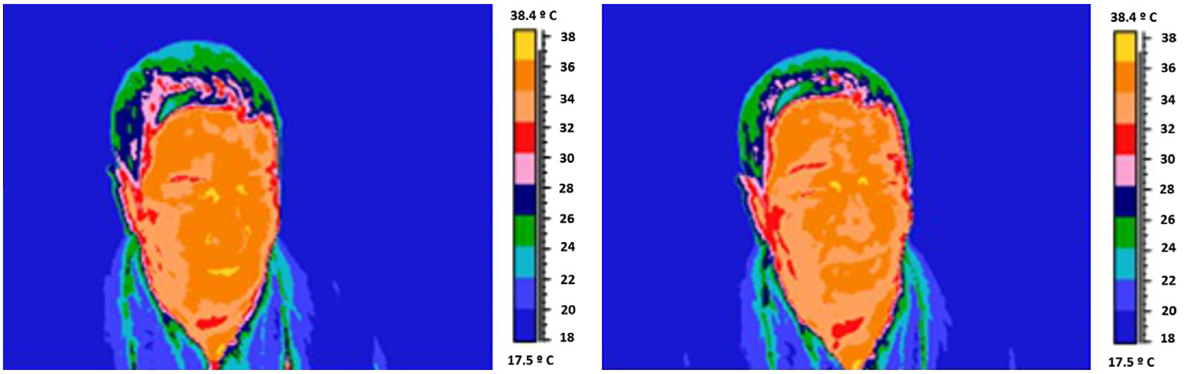

Fig. 2A. Changes in the temperature of the face when observing negative valence and low arousal IAPS images (right), which reflects a decrement in the temperature of the nose, when compared to the baseline condition (left).

2.1.4.2. Experiment 1.b. The arousal was manipulated between groups to avoid sequential effects.[7] Half of the subjects, $N = 20$, viewed the low arousal images randomly mixed, meaning *Set 1* and *Set 2*, and the other half saw the high arousal ones, *Set 3* and *Set 4*, randomly mixed. *Set 2b* or the neutral condition was presented 10 min before the experimental condition to half of the participants and 10 min after to the rest.

2.2. Results and discussion

The range of temperatures registered with the camera in our experiments run between 18 °C and 40 °C. We tested a neutral condition with respect to the baseline face temperature and found no significant thermic changes in all our sample ($MD = 0.3$, $SD = 0.4$, $t(119) = 0.25$, $p = .8$). In this section we present the comparison between experimental conditions, *Set 1*, *Set 2a*, *Set 3* and *Set 4* and the neutral condition *Set 2b*. Nevertheless, the result pattern does not change if the comparison is between the experimental conditions and the baseline.

2.2.1. Valence effect (Experiment 1.a)

We found a significant decrement, for negative images with low arousal (*Set 2*, $M = 0.85$ °C, $SD = 0.4$, $t(9) = 3.25$, $p < .001$) measured on the tip of the nose with respect to the neutral condition (see Fig. 2A). Some participants (30%) also displayed a not significant general decrement in the temperature of the face (overall nose, mouth and forehead) for IAPS images of negative valence and low arousal ($t(9) = 0.70$, $p = .25$); while 50% of them showed thermal increments, the results were still not significant ($t(9) = 1.38$, $p = .1$). For negative images with high arousal (*Set 4*) we found a significant thermal increment with respect to the neutral condition ($M = 0.96$ °C, $SD = 0.5$), $t(9) = 3.56$, $p = .003$, see Fig. 2A). In general, we found no significant thermal changes for negative images with low and high arousal analyzed together ($M = 0.5$ °C, $SD = 0.8$, $t(19) = 1.3$, $p = .1$).

Regarding data for the images with positive valence, we found a general significant thermal change of $M = 1.3$ °C ($SD = 0.5$, $t(19) = 5.34$, $p < .001$). The thermal increment was greater for Set 3, which is the high arousal condition ($M = 1.66$ °C, $SD = 0.3$, $t(9) = 6.18$, $p < .001$); this increment was lower although significant for Set 1, positive images with low arousal ($M = 1.01$ °C, $SD = 0.6$, $t(9) = 3.66$, $p = .002$, see Fig. 2B); we compared these two sets and found that the difference was significant ($t(19) = 3.51$, $p < .001$, see Table 2).

2.2.2. Arousal effect (Experiment 1.b)

We found a significant increment in the temperature of the tip of the nose for the group where IAPS images of high arousal were presented, with positive and negative valence mixed trial by trial, with respect to the neutral condition ($M = 1.25$ °C, $SD = 0.6$, $t(19) = 4.33$, $p < .001$). However, in 40% of the participants the temperature also increased in the mouth and forehead (see Fig. 2C), although the thermal changes were not significant ($t(19) = 1.06$, $p = .15$). No significant thermal changes occurred in the low arousal condition, where positive and negative images were randomly mixed, ($M = 0.6$ °C, $SD = 0.7$, $t(19) = 0.86$, $p = .2$). The difference in valence between the low and high arousal groups was not significant ($t(19) = 0.9$, $p = .16$).

The results of Experiment 1.b confirms again that there are two emotional effects. The valence effect, where there is a facial thermal increment with positive images, and the arousal effect, where there is a facial thermal increment with arousal.

[7] In order to explain the difference between this experiment and the previous one it is important to notice that there are no emotional stimuli with high arousal components and neutral valence, nor low arousal and neutral valence apart from the stimuli of daily life that are neutral for both characteristics (Mata Martín, 2006). Then, the manipulation of the arousal needs to be between groups again, while the valence could be fixed or mixed within each group. Our pilot studies indicate that mixed valence promotes the thermic difference between groups with high arousal and low arousal, a result with the same direction in both cases (fixed or mixed valence intra group). Therefore in Experiment 1.a we manipulate the valence between groups, while in Experiment 1.b the arousal is manipulated between groups.

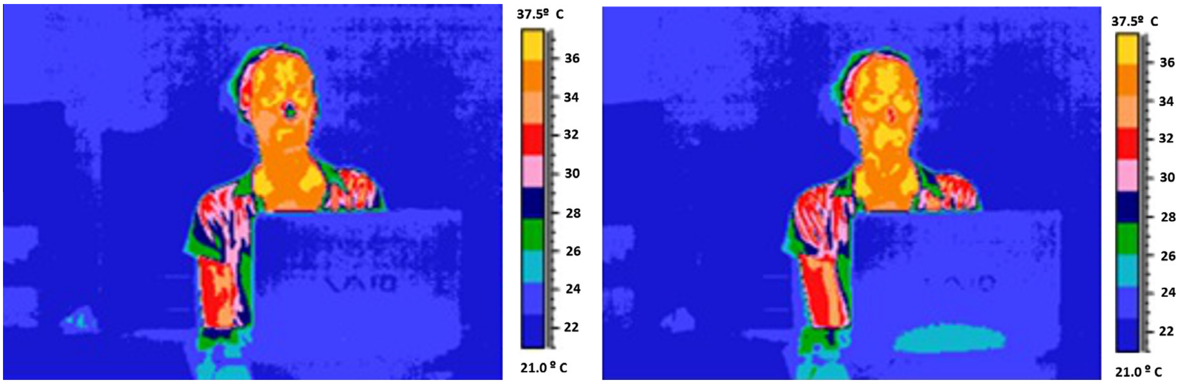

Fig. 2B. Changes in the temperature of the face when presented positive valence and high arousal IAPS images (right), which reflects an increment in the temperature of the nose (and frequently also in forehead and mouth), when compared to the baseline condition (left).

Table 2
Direction of thermal changes for the experimental sets of IASP images.

Thermal changes for IASP images	Low arousal	High arousal
Positive valence	Set 1: thermal increment (1.0 °C)	Set 3: thermal increment (1.6 °C)
Negative valence	Set 2: thermal decrement (−0.8 °C)	Set 4: thermal increment (0.9 °C)

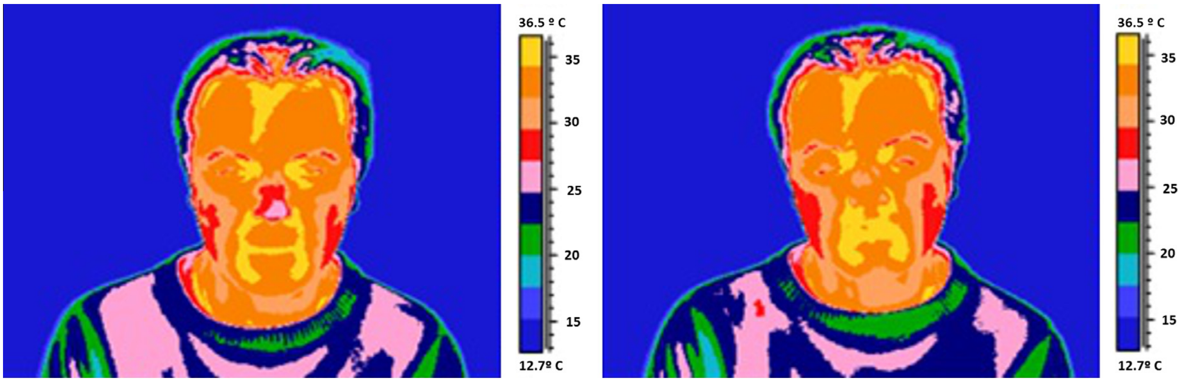

Fig. 2C. While experiencing high arousal stimuli (right), the temperature increased in the nose and mouth for images of positive and negative valence, compared with the baseline condition (left).

Both effects can interact, leading to thermal increments in the tip of the nose when presented high arousal and generally positive valence images or leading to thermal decrements when presented low arousal and generally negative valence images. However, this last effect, thermal decrement with low arousal, does not appear in the mixed valence condition, low arousal with positive and negative images, such as in Experiment 1.b. Arousal is related to higher temperatures in the nose or face, while valence (generally negative valence) is attributed to lower temperatures. In addition, sadness, negative valence and low arousal, may be associated with lower temperatures in the face while happiness, positive valence and high arousal, may be associated with higher temperatures in the face. In general, thermal facial changes seem to correlate more with arousal than with valence. In short, a valence effect was only observed under low arousal conditions. However, the arousal effect happened in qualitative form for negative images, which means thermal decrements for low arousal images and thermal increments for high arousal images; in quantitative form for positive images: the thermal increment was greater for high arousal images in Experiment 1.a.

3. Experiment 2. Emotional contagion tasks (of laughter or empathic pain)

In this series of experiments we study the thermal imprint (somatic markers) of empathy, which shows different constructs associated with positive or negative valences like empathic stress and empathic happiness. Tullet (2012) maintains that empathy reactions can reflect slight motivation or the idea that empathy is positively related to fear but negatively related to anger. However, Wei, Liao, Ku, and Shaffer (2011) found that empathy was positively associated with the emotion of happiness and a sense of well-being. According to the previous literature relating lower temperatures to negative emotions and higher temperatures to positive emotions, when we examine empathy related to fear we would expect lower temperatures on the tip of the nose; while with empathy related to happiness, we would expect a higher temperature on the tip of the nose. The relationship between empathy and arousal is also complex (Batson, Fultz, & Schoenrade, 1987): to avoid personal distress and focus on the self or empathic over-arousal, the vicariously induced emotion is attenuated, which means that for participants with high empathy, a faster decline in arousal may occur (Bogdanov et al., 2013). The activation level of the insula and the anterior cingulated cortex while experiencing empathy may depend on the perspective adopted, as shown in Lamm, Batson, and Decety (2007). These authors found a negative correlation between empathic concern and personal distress and higher empathic concern in the condition "other perspective" than in the "self perspective" condition for pain. In other words, if empathy is associated with high arousal, we would expect higher temperatures on the tip of the nose, but if it is associated with low arousal, then we would expect a lower tip of the nose temperature. To summarize, it is not possible to determine, a priori, the relationship between low or high empathy levels with increments or decrements of the temperature of the tip of the nose, or to know whether this relationship depends more on arousal or valence. Our proposal, regarding the results of Experiment 1, is that empathy constitutes an attenuated arousal, and if the thermal change under low arousal depends on valence, as our previous results indicate, it is possible to hypothesize that under negative empathy conditions a thermal decrement occurs and under positive empathic conditions a thermal increment.

3.1. Method

3.1.1. Participants

3.1.1.1. Experiment 2.a. Empathic happiness: 50 university students (25 women), between 22 and 31 years of age ($M = 25.3$, $SD = 2.8$); 20 participants were selected according to TECA score, 10 above percentile 70 and 10 below percentile 30.

3.1.1.2. Experiment 2.b. Empathic stress: 50 different university students (30 women), between 23 and 32 years of age, ($M = 26$, $SD = 2.8$); 20 participants were selected according to TECA scores, 10 above percentile 70 and 10 below percentile 30.

The same conditions as in Experiment 1 were employed for the informed consent and the inclusion/exclusion criteria.

3.1.2. Stimuli

3.1.2.1. Experiment 2.a. The stimuli were video clips of people laughing at other people under different conditions to trigger positive empathy responses: for example, people who had fallen without badly hurting themselves, babies laughing with their parents or with family pets, or groups of people laughing together displaying happiness and love. An additional video that presented jokes was the control condition; it contained positive humor but no empathy cues. Each condition lasted 5 min.

3.1.2.2. Experiment 2.b. There were three different stimuli. The first was a neutral video presenting a seated person waiting. The second was a video of this person suffering a painful stimulation, which we call the "pain in the third person perspective". The third condition consisted of a direct physical stimulation of the participant, who received the same painful stimuli as shown in the second condition, called "pain in the first person perspective". We employed a non-dangerous electric dog collar called "Canicom200", attached as a wristband on the forearm of our participants, to apply pain; the device has two electrodes that shocked the participants, discharging the second intensity level for 2 s. Each video condition lasted 5 min.

To validate the rating of the videos, they were rated in valence (0–9 points) and arousal (0–9 points), following the SAM (same procedure employed for IAPS in Experiment 1). The positive videos scored $M = 7.3$ ($SD = 0.9$) in valence and $M = 6.5$ ($SD = 0.4$) in arousal, while the negative or painful ones scored $M = 3.4$ ($SD = 0.3$) in valence and $M = 7.1$ ($SD = 0.5$) in arousal.

3.1.3. Equipment

We employed the same apparatus as described in Section 2.1, *Equipment*.

3.1.4. Self-reported measures

The Cognitive and Affective Empathy Test (TECA) by López Pérez, Fernández Pinto, and Abad (2008) was used to measure empathy based on general values and four subscales: Perspective Adoption (AP), the capacity to place oneself in the shoes of another (as though in the third person view or perspective); Emotional Understanding (CE), the capacity to understand other people's emotions, intentions and impressions (as though in the first person view or perspective); Empathic Stress (EE), the ability to be in tune with others' negative emotions; and Empathetic Happiness scale (AE), the ability to feel others' positive emotions.

3.1.5. Procedure and setting

3.1.5.1. Experiment 2.a. Empathic happiness: The procedure for this experiment was similar to the one employed in Experiment 1 (see Section 2.1 *procedure and Settings*). After watching the videos, participants were asked to evaluate the humor of the videos, using a scale (our design) that went from 0 to 10 points, 0 being not funny at all and 10 being very funny; the resultant average score was $M = 7.5$ ($SD = 2.2$) for all the videos presented. Participants rated the jokes $M = 6.2$ ($SD = 3.3$). At the end of the experiment, they completed the TECA test (López Pérez et al., 2008).

3.1.5.2. Experiment 2.b. Empathic stress: The procedure for this experiment was similar to the one employed in Experiment 1 (see Section 2.1 *procedure and Settings*).

3.2. Results and discussion

3.2.1. Empathic happiness (Experiment 2.a)

For the 20 participants selected due to their TECA scores, we found a significant correlation between TECA global score and humor score for the videos of people who laughed ($r = .57$, $p = .003$) in the first part of the experiment but not for the videos with the jokes ($r = .31$, $p = .1$).

The 10 participants included in the high empathy group exhibited the following average empathy values: Adoption of Perspectives $M = 34$ ($SD = 4$), Emotional Comprehension $M = 37$ ($SD = 5$), Empathic Stress $M = 31$ ($SD = 3$), Empathic Happiness $M = 39$ ($SD = 8$), global score $M = 141$ ($SD = 12$). The remaining 10 participants were in the low empathy group and had the following empathic values: Adoption of Perspectives $M = 27$ ($SD = 6$), Emotional Comprehension $M = 22$ ($SD = 8$), Empathetic Stress $M = 25$ ($SD = 11$), Empathetic Happiness $M = 22$ ($SD = 15$), global score $M = 96$ ($SD = 7$). The difference in global empathy between the groups was significant ($t(19) = 8.52$, $p < .001$). The interaction between groups (low or high empathy) and pre- and post-thermal change was significant ($F(1,18) = 18.54$, $p < .001$. The mean of the temperature of the tip of the nose during the pre-test for the high empathy group was 33.3 °C ($SD = 1.1$), the post-test value was $M = 32.2$ °C ($SD = 0.8$), and it was possible to demonstrate a significant pre-test vs post-test difference ($t(9) = 3.18$, $p = .007$). Thermal changes were observed only while participants watched videos of contagious laughter, but no significant change in the temperature of the nose was observed during the video that required participants to read jokes, where pre-test mean was 33.2 °C ($SD = 0.9$) and post-test mean was 33.3 °C ($SD = 1.3$). For the low empathy group, the mean of the pre-test temperature was 33.4 °C ($SD = 1.4$) and the post-test temperature was $M = 32.9$ °C ($SD = 1.6$), while watching videos of contagious laughter, which did not lead to a significant difference ($t(19) = 0.68$, $p = .25$). The decrement in the nose temperature of the participants in the high empathy group had a mean of 1.4 °C ($SD = 0.8$), and the average decrease among participants of the low empathy group was 0.7 °C ($SD = 0.3$). The difference in the change of temperature of the tip of the nose between participants of the high empathy group vs the low empathy group was significant ($t(19) = 4.26$, $p < .001$). Fig. 3A shows the change in temperature in a participant of the high empathy group before and after watching the contagious laughter video. Significant correlations were found for the change in temperature of the tip of the nose, when measuring global empathy and empathic happiness ($r = .7$ and $r = .73$, $p = .01$ respectively). In short, contagious positive emotions produce a lower temperature on the nose in relation to one's empathy levels.

3.2.2. Empathic pain (Experiment 2.b)

We used the TECA test to measure the empathy levels of each participant. Ten participants expressed high empathy levels (global score $M = 138$, $SD = 17$) and 10 participants expressed low empathy levels (global score $M = 91$, $SD = 11$). The resulting difference was significant ($t(19) = 5.46$, $p < .001$). The interaction between group and thermal change was significant ($F(1,18) = 13.87$, $p < .001$). For participants in the high empathy group, the change in the temperature of the nose experienced in the first person condition was $M = 1.3$ °C ($SD = 0.8$) and the change in the third person condition was $M = 1.1$ °C ($SD = 0.5$). Among participants of the low empathy group, the change in the temperature of the nose produced in the first person condition was $M = 0.9$ °C ($SD = 0.3$) and a change of $M = 0.7$ °C ($SD = 0.4$) was produced in the third person condition. Accordingly, there was a greater change in temperature in participants in the high empathy group than in those of the low empathy group ($t(19) = 4.62$, $p < .001$). A similar change in temperature was observed in the first and third person conditions for participants in the high empathy group. However, participants in the low empathy group experienced a greater change in temperature in the first person pain condition vs the third person condition ($t(9) = 2.15$, $p = .03$). In short, pain in the first and third person perspectives generally produces a lower nose temperature in participants with high empathy (see Fig. 3B).

These results suggest that valence, positive or negative, is not relevant for the change in nose temperature in relation to empathy. In all cases, laughter or pain, empathy is associated with lower temperatures on the tip of the nose. In some subjects, other areas like the forehead or cheeks also showed thermal decrements. There seems to be a consensus that low arousal is associated with lower temperature on the tip of the nose and high arousal with higher nose temperature. Thus, the results of this experiment show that thermal changes associated with empathy are more related to (low) arousal than to valence.

4. Experiment 3. The thermal imprint of subjective experience felt in the body and face following Nummenmaa et al. (2014): the case of Love

Emotions are often felt in the body and face, where physiological changes arise from emotional states. Nummenmaa et al. (2014) reveal maps of bodily sensations associated with different emotions using a unique topographical self-report method, where the participants were shown two silhouettes of bodies alongside emotional words, stories, movies, or facial

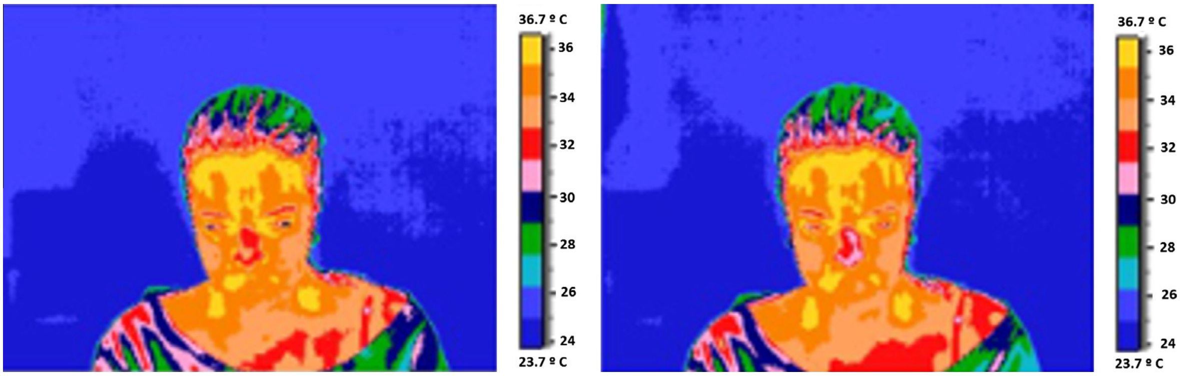

Fig. 3A. Baseline condition (left) compared with the contagious laughter condition (right) shows a decrement in the temperature of the nose.

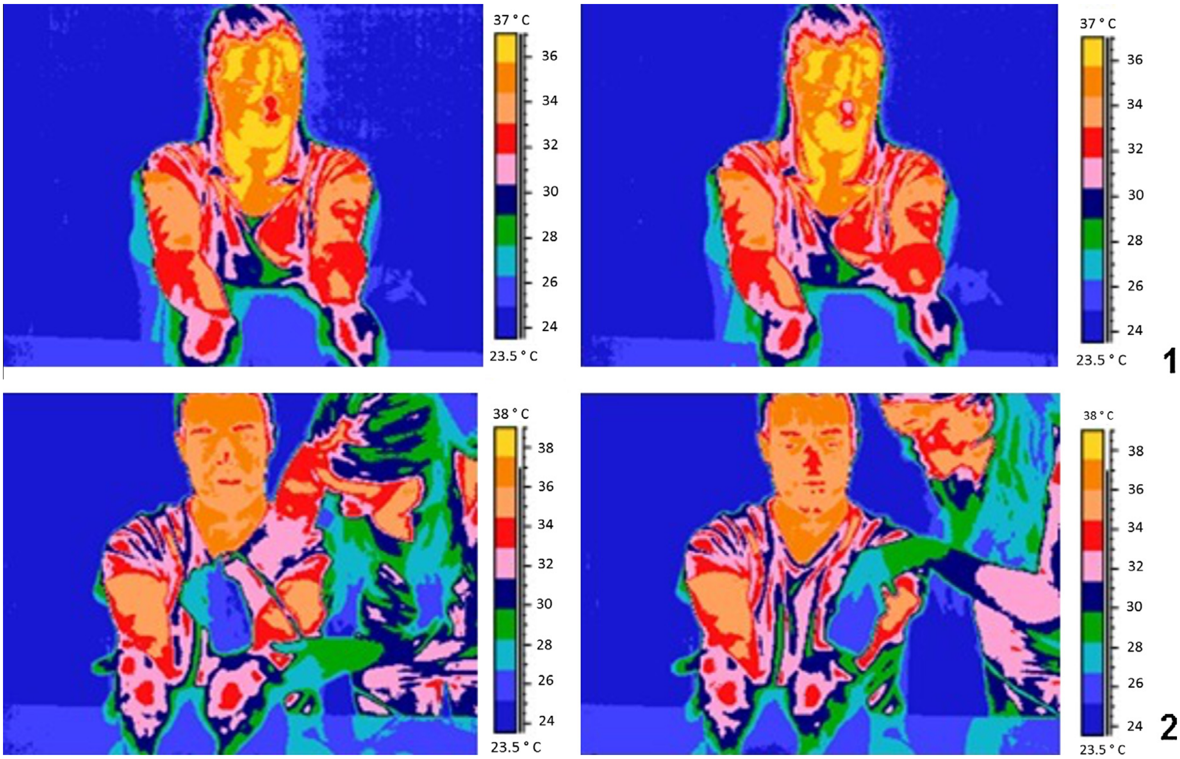

Fig. 3B. 1. Participant with high empathy showing a lower nose temperature while observing pain (upper right) compared with at rest (upper left). 2. Participant suffering pain displaying a lower temperature on the nose and cheeks (lower right) compared with rest (lower left).

expressions. They were asked to color the bodily regions whose sensations, such as warmth, for example, they felt increasing or decreasing while viewing each stimulus. Different emotions were consistently associated with statistically separable bodily sensation maps. For example, love and happiness were related to subjective higher facial and body temperature (activation) but depression was linked to colder body and face, and anxiety with hot face and cold hands and arms. In accordance with our goal, the question is whether these subjective sensations correlate with real thermal changes; therefore, we are trying here to answer the question about love, concretely exploring romantic passion and Love of God among the many types of love (Fisher et al., 2002).

4.1. Method

4.1.1. Participants

4.1.1.1. Experiment 3.a. Love of God: For this study we recruited 30 participants: 15 Spanish Catholics (12 women), who said they loved God too much and felt this love in their face and body when having a religious experience, and 15 non-believers (7 women). The believers, all of whom have a university background, were recruited in a local religious community school and are between 25 and 56 years of age, ($M = 35.4$, $SD = 9.6$).

4.1.1.2. Experiment 3.b. Romantic passion: 12 Heterosexual couples between 21 and 28 years of age ($M = 24$, $SD = 2.3$), studying at university and who have been together in a romantic relationship for less than 1 year ($M = 8$, $SD = 2.5$ months), and said that they had felt passionate love at first sight. They were recruited after answering a notice posted on a university bulletin board.

The same conditions as in Experiment 1 were employed for the informed consent and the inclusion/exclusion criteria.

4.1.2. Stimuli

4.1.2.1. Experiment 3.a. Love of God: The stimuli were 10 min video clips showing typical Spanish Easter Week "Semana Santa" activities, religious images and celebrations in their own church communities.

4.1.2.2. Experiment 3.b. Romantic passion: The stimuli were two 5 min presentations, one with portraits of the beloved (experimental condition: with love in memory) and the other with portraits of a friend of the opposite gender (control condition: with friendship in memory).

To validate the rating of the religious videos and the portraits of the beloved person, the clips were rated in valence (0–9 points) and arousal (0–9 points), following the SAM (same procedure employed for IAPS in Experiment 1). In all cases, the result was high arousal and positive valence ($M = 8.3$, $SD = 0.5$ vs $M = 7.7$, $SD = 0.7$ for valence and $M = 8.1$, $SD = 0.3$ vs $M = 7.9$, $SD = 0.8$ for arousal).

4.1.3. Equipment

We employed the same apparatus as described in Section 2.1, *Equipment*.

4.1.4. Procedure and setting

The procedure for this experiment was similar to the one employed in Experiment 1 (see Section 2.1 *procedure and Settings*) for the presentation of the stimuli and the thermographic recordings (baseline and experimental conditions).

4.1.4.1. Experiment 3.a. Love of God: During the stimuli presentation, the participants were asked to pray (the Lord's prayer) with their inner voice and also to make personal prayers. Additionally, they answered using the topographical self-report method of Nummenmaa et al. (2014) that consists of showing two silhouettes of bodies alongside emotional words related to Love of God; the participant was requested to color the bodily regions where they felt increases or decreases in activation while viewing each stimulus.

4.1.4.2. Experiment 3.b. Romantic passion: In this series, the participants were asked to look at the eyes of the portraits of the beloved one or a friend during the thermographic measurement, while thinking of the person in the stimuli presentation. The experimental and control condition were counterbalanced with an inter-task period of 10 min. In this particular experiment, the hands were also measured with thermography.

4.2. Results and discussion

4.2.1. Experiment 3.a: Love of God

Employing the method of Nummenmaa et al. (2014) with our participants to illustrate their subjective experience of love in the face after the experimental session, it was found that love (of God) tends to be experienced as general face activation.

In relation to thermal images taken during The Lord's Prayer or personal praying, we observed that Catholic believers showed a decrease in the temperature of the nose ($M = 1.1$ °C, $SD = 0.7$, $t(14) = 3.15$, $p = .005$), during The Lord's Prayer but a general increase in the temperature of the face (nose included) during personal praying ($M = 1.6$ °C, $SD = 0.4$, $t(14) = 4.45$, $p < .001$, see Fig. 4A.).

Non-believers showed no subjective and thermal face changes with respect to the baseline, and particularly for nose temperature the thermal change was not significant ($M = 0.3$ °C, $SD = 0.5$, $t(14) = 0.8$, $p = .2$).

4.2.2. Experiment 3.b: romantic love

We found a general increase in temperature in the face, as predicted by the Nummenmaa et al. (2014) method for assessing subjective activation, in the experimental condition compared to the baseline and control condition ($M = 1.5$ °C, $SD = 0.5$, $t(14) = 5.67$, $p < .001$), as expected from the subjective experience of the new couples. This thermal increment was similar to the general increment found in Experiment 3.a for the "Love of God" condition (see Fig. 4B). In this case, there was not only an increment in the temperature of the face for most of the participants, but also an increment in the temperature of the hands for half of the participants.

In this series of experiments, we have shown that feelings of love trigger high arousal and positive valence emotions, and that the type of love does not matter, at least for romantic and religious experiences of love. In all cases, it is associated with

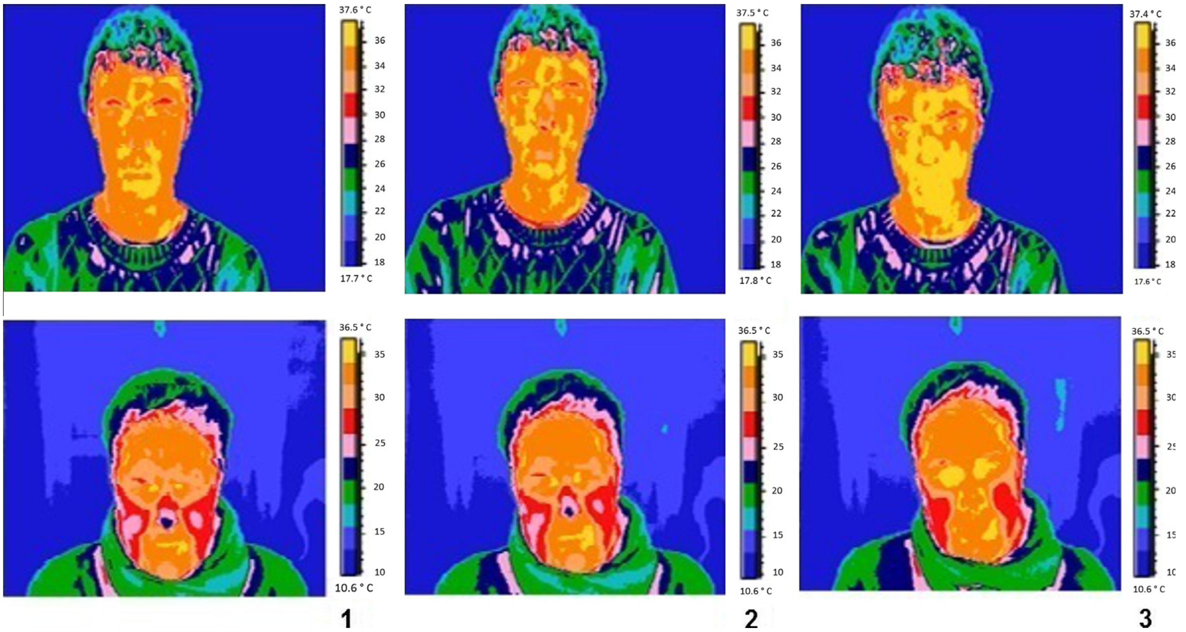

Fig. 4A. Thermograms of two believing participants in the conditions. 1. At rest (baseline). 2. During the Lord's Prayer. 3. Making a personal prayer.

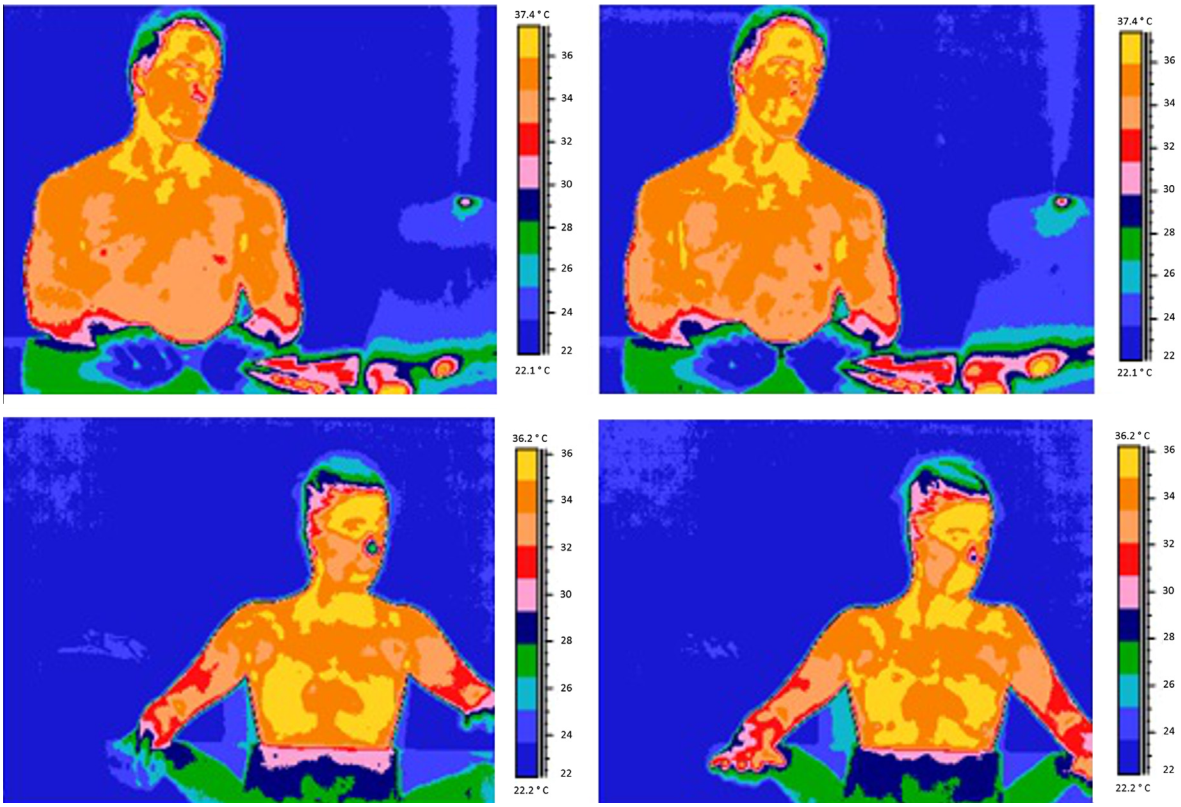

Fig. 4B. Male (upper) and female (lower) participants present a general activation in the face when comparing baseline (left) with emotional condition of romantic love (right).

warm face in subjective and physiological terms. Thus, temperature can be considered a sensitive dependent variable and could be a somatic marker of a subjective experience, love in our case.

5. General discussion

To summarize, in our series of studies, working with young adults from the normal population and with standard stimuli and tests from psychology of emotions, we methodically examine the valence effect, arousal effect, empathy effects, and qualia. Here, we present the technique of thermography to measure a possible somatic marker for subjective experiences, such as basic emotions, pain, empathy or love; we argue that thermography is an instrument of potential interest for application to studies of consciousness, emotions and subjective experiences. The thermal corporal changes, measured mainly in the face in our studies, are sensitive to the manipulation of independent psychological variables of emotional type. We focused on facial temperature, with special attention to the tip of the nose, the part of the face most sensitive to changes in temperature and psychological manipulation, and the temperature of the forehead, the part of the face least sensitive to changes in temperature and psychological manipulation.

Previous results on the relationship between positive and negative emotions and thermal increments or decrements in different parts of face and body were sometimes conflicting. As we reported in the introduction, Briese and Cabanac (1991) found that stress levels correlate with increased blood flow in the forehead, while Nagumo et al. (2002) obtained correlations between arousal level and nasal skin temperature. Zenju et al. (2004), as well as Nakayama et al. (2005) and Kuraoka and Nakamura (2011) referred to the increasing temperature of the nose when manipulating conditions to obtain a pleasant mental state, and a drop in temperature when triggering an unpleasant state. In contrast, Nakanishi and Imai-Matsumura (2008) also observed facial skin temperature decrements during joyful expressions on the nose of children, while Robinson et al. (2012) found that the increase in temperature of brows and cheeks is related to a negative emotional valence but when measuring it in the area surrounding the eye it is related to positive feelings.

Our main concerns were to clarify conflicting conclusions from previous studies about: (1) whether or not thermography is a effective physiological index to study emotions; (2) whether or not the impact of valence and arousal manipulations on thermal changes in the face are confounded or mixed due to interactions between these two basic dimensions of emotion in the previous experimental manipulations; and (3) distinguishing the basic dimensions of emotion, empathy and feelings through thermographic measurements, which were sometimes inappropriately compared between them. Our results support the hypothesis that thermography is a valid index for emotion, empathy and feelings. The thermal impact of valence and arousal can be successfully differentiated and be employed to predict the thermal effect of these parameters based on their value in these basic dimensions. In the emotional tasks reported here, the temperature of the nose increased with positive valence and increasing arousal. In the mixed conditions, arousal seems to be the main factor. In high arousal and negative IAPS images circumstances, we obtained thermal increments. The valence effect is clear only in the case of the low arousal condition, while we located thermal increments for positive and low arousal IAPS images and thermal decrements for negative and low arousal images.

Particularly in the tasks of emotional contagion associated with an empathic response, the temperature of the nose decreased, for example during tasks in which the participants laughed while watching funny videos or watched others suffering pain. The thermal reduction with empathy may be related to a lower arousal for high empathic participants to avoid distress. With regard to the contagiousness of laughter and pain, it is interesting to observe that despite dealing with emotions of opposite valence, the temperature of the nose decreased in both cases and that the change in temperature appears to be associated with participants' empathy levels. In the pain condition, the change in temperature is greater, but similar in the first and third person experience only for participants with high empathy, and lower but still measurable in first person experience for those with low empathy.

However, if we compare the thermal pattern of the emotional contagion to the thermal pattern for feelings, love here, we observe that the temperature of the nose changes in the group of those who feel Love of God. Nose temperature increased during personal prayer but decreased during the Lord's Prayer, only for believers, but it remains constant in non-believers during praying. When experiencing Love of God in believers and romantic love in couples, the general subjective activation felt in the face, following Nummenmaa et al. (2014), corresponds to a general increment in the temperature of the face. In the case of passion or love at first sight, a general increment of the temperature in different areas of the superior part of the body (face, hands and breast in some cases) was registered but not in the inferior part. Accordingly, subjective experience can be associated with thermal imprints, also known as somatic markers.

These results lead us to reject the general idea that a quale (Hochel et al., 2007) could only be a manifestation of empathy toward subjects, objects or ideas, since when having an empathic response the temperature drops, but when experiencing love it increases. In any case, thermography can generally be used to determine whether a person who says "I love you" really means it or not.

Traditionally, in the linguistic metaphors used when speaking about emotions, it has been said that anger is related to a hot face or higher temperature (red: to flare up with rage) and fear with cold or lower temperatures (blue: to become pale) in the hands and face in general. In the near future, we will explore thermal imprints of the body and face for other subjective experiences, such as anxiety, phobias, fear or anger. Thus, thermography is a useful tool with great potential for tackling scientific and philosophical questions regarding subjective experiences, mental states and emotions.

Nevertheless, we recognize that the main limitations of our research are the number of participants, the small number of thermographic studies, the need to improve and standardize protocols about researching in medicine and psychology with thermography. Therefore we predict that this field will improve thanks to the addition of new studies that correlate thermographic measures with brain image, other well-established physiological measures and reaction time task results in the future.

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References

Agnew, Z., & Wise, R. J. S. (2008). Separate areas for mirror responses and agency within the parietal operculum. *The Journal of Neuroscience, 28*(47), 12268–12273. http://dx.doi.org/10.1523/jneurosci.2836-08.2008.

Batson, C. D., Fultz, J., & Schoenrade, P. A. (1987). Distress and empathy: Two qualitatively distinct vicarious emotions with different motivational consequences. *Journal of Personality, 55*(1), 19–39.

Bogdanov, V. B., Bogdanova, O. V., Gorlov, D. S., Gorgo, Y. P., Dirckx, J. J., Makarchuk, M., et al (2013). Alexithymia and empathy predict changes in autonomic arousal during affective stimulation. *Cognitive and Behavioral Neurology, 26*(3), 121–132.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*, 49–55.

Briese, E., & Cabanac, M. (1991). Stress hyperthermia: Physiological arguments that it is a fever. *Physiological Behavior, 49*, 1153–1157.

Chlebicka, I., Matusiak, L., Baran, E., & Szepietowski, J. (2012). Freezing fingers syndrome, primary and secondary Raynaud's phenomenon: Characteristic feature with hand thermography. *Acta Dermato-Venereologica, 93*(4), 428–432.

Dimberg, U., Andréasson, P., & Thunberg, M. (2011). Emotional empathy and facial reactions to facial expressions. *Journal of Psychophysiology, 25*(1), 26–31.

Ekman, P. (1970). Universal facial expressions of emotion. *California Mental Health Research Digest, 8*(4), 151–158.

Fisher, H., Aron, A., Mashek, D., Strong, G., Li, H., & Brown, L. L. (2002). Defining the brain systems of lust, romantic attraction and attachment. *Archives of Sexual Behavior, 31*(5), 413–419.

Genno, H., Ishikawa, K., Kanbara, O., Kikumoto, M., Fujiwara, Y., Suzuki, R., et al (1997). Using facial skin temperature to objectively evaluate sensations. *International Journal of Industrial Ergonomics, 19*(2), 161–171.

González Montalvo, J. L. (1991). *Creación y validación de un test de lectura para el diagnóstico del deterioro mental en el anciano*. Doctoral Thesis, Universidad Complutense de Madrid, Espana.

Hochel, M., Milan, E. G., Gonzalez, A., Tornay, F., McKenney, K., Diaz Caviedes, R., et al (2007). Experimental study of phantom colours in a colour blind synaesthete. *Journal of Consciousness Studies, 14*(4), 75–95.

Jarlier, S., Grandjean, D., Delplanque, S., ŃDiaye, K., Cayeux, I., Velazco, M. I., et al (2011). Thermal analysis of facial muscles contractions. *IIEE Transactions on Affective Computing, 2*(1).

Jenkins, S., Brown, R., & Rutterford, N. (2009). Comparing thermographic, EEG and subjective measures of affective experience during simulated product interactions. *International Journal of Design, 3*(2), 53–65.

Khan, M. M., Ward, R. D., & Ingleby, M. (2006). Infrared thermal sensing of positive and negative affective states. In *Paper presented at the conference on robotics, automation and mechatronics*, Bangkok.

Khan, M. M., Ward, R. D., & Ingleby, M. (2009). Classifying pretended and evoked facial expressions of positive and negative affective states using infrared measurement of skin temperature. *ACM Transactions of Applied Perception, 6*(1), 1–22. http://dx.doi.org/10.1145/1462055.1462061.

Konings, M., Bak, M., Hanssen, M., Van Os, J., & Krabbendam, L. (2006). Validity and reliability of the CAPE: A self-report instrument for the measurement of psychotic experiences in the general population. *Acta Psychiatrica Scandinavica, 114*(1), 55–61. http://dx.doi.org/10.1111/j.1600-0447.2005.00741.x.

Kuraoka, K., & Nakamura, K. (2011). The use of nasal skin temperature measurements in studying emotion in macaque monkeys. *Physiology Behaviour, 1*(102), 347–355.

Lamm, C., Batson, C. D., & Decety, J. (2007). The neutral substrate of human empathy: Effects of perspective-taking and cognitive appraisal. *Journal of Cognitive Neuroscience, 19*(1), 42–58. http://dx.doi.org/10.1162/jocn.2007.19.1.42.

Lang, P. J. (1995). The emotion probe: Studies of motivation and attention. *American Psychologist, 50*, 371–385. http://dx.doi.org/10.1037/0003-066X.50.5.372.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). *International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual (Technical Report No. A-6)*. Ganesville, FL: University of Florida, Center for Research in Psychophysiology.

López Pérez, B., Fernández Pinto, I., & Abad, F. J. (2008). *TECA. Test de empatía cognitiva y afectiva*. Madrid.

Mata Martín, J. L. (2006). *Mecanismos atencionales y preatencionales de los reflejos defensivos*. Doctoral Thesis, University of Granada, Granada, Spain.

Mize, T. D., & Myers, T. (2011). Exploring racial differences on the measurement and experience of emotion. *The Journal for Undergraduate Research Opportunities*.

Moltó, A., Montañes, S., Poy, R., Segarra, P., Pastor, M. C., Tormo, M. P., et al (1999). Un nuevo método para el estudio experimental de las emociones: el IASP adaptación española. *Revista de psicología general y aplicada, 52*(1), 55–87.

Nagumo, K., Zenju, H., Nozawa, A., Ide, H., & Tanaka, H. (2002). Evaluation of temporary arousal level using thermogram images. In *Paper presented at the 19th remote sensing forum*, 3 March, Tokyo, Japan.

Nakanishi, R., & Imai-Matsumura, K. (2008). Facial skin temperature decreases in infants with joyful expression. *Infant Behavior & Development, 31*, 137–144. http://dx.doi.org/10.1016/j.infbeh.2007.09.001.

Nakayama, K., Goto, S., Kuraoka, K., & Nakamura, K. (2005). Decrease in nasal temperature of rhesus monkeys (macaca mulatta) in negative emotional state. *Journal of Physiology and Behavior, 84*, 783–790. http://dx.doi.org/10.1016/j.physbeh.2005.03.009.

Nummenmaa, L., Glerean, E., Hari, R., & Hietanen, J. K. (2014). Bodily maps of emotions. *Proceedings of the National Academy of Sciences of the United States of America, 111*(2), 646–651. http://dx.doi.org/10.1073/pnas.1321664111.

Or, C. K. L., & Duffy, V. G. (2007). Development of a facial skin temperature-based methodology for non-intrusive mental workload measurement. *Occupational Ergonomics, 7*(2), 83–94.

Pavlidis, I., Eberhardt, N. L., & Levine, J. A. (2002). Human behaviour: Seeing through the face of deception. *Nature, 4*, 35. http://dx.doi.org/10.1038/415035a.

Poppendieck, W., Ruff, R., Fernández, E., & Hoffman, K. P. (2009). Measurement station for recording of different biosignals to detect emotions under mobile conditions. In *Paper presented at the Mobile HCI' 09*, 15–18 September, Bonn, Germany.

Ring, E. F. J., & Ammer, K. (2000). The technique of infra red imaging in medicine. *Thermology International, 10*(1), 7–14.

Robinson, D. T., Clay-Warner, J., Moore, C. D., Everett, T., Watts, A., Tucker, T. N., et al (2012). Toward an unobtrusive measure of emotion during interaction: Thermal imaging techniques. In W. Kalkhoff, S. R. Thye, & E. J. Lawler (Eds.). *Biosociology and neurosociology – Advances in group processes* (Vol. 29, pp. 225–266). Emerald Group Publishing Limited.

Sheba, J. K., Elara, M. R., Lerín, E., Martínez-García, E. A., & Torres-Córdoba, R. (2012). Comparing thermography, GSR and heart rate during stimulated therapeutic PET root interaction among elderly. In *Paper presented at the 8th international conference on intelligent unnamed systems*, 22–24 October, Singapore.
Stoll, A. M. (1964). Techniques and uses of skin temperature measurements. *Annals of the New York Academy of Sciences, 121*(1), 49–56. http://dx.doi.org/10.1111/j.1749-6632.1964.tb13684.x.
Tanaka, H., Ide, H., & Nagashima, Y. (1999). Attempt of feeling estimation by analysis of nasal skin temperature and arousal level. *Transaction of Human Interface Society, 1*, 51–56.
Tullet, A. M. (2012). *Withdrawal motivation and empathy: Do empathic reactions reflect the motivation to "reach out" or the motivation to "get out"?*. Doctoral Thesis, University of Toronto.
Veltman, J. A., & Vos, W. K. (2005). Facial temperature as a measure of operator State. In *Paper presented at the 11th international conference on human–computer interaction*, 22–27 July, Las Vegas-Nevada, USA.
Vila, J., Sánchez, M., Ramírez, I., Fernández, M. C., Cobos, P., Rodríguez, S., et al (2001). El sistema internacional de imágenes afectivas (IAPS): Adaptación española. Segunda parte. *Revista de psicología general y aplicada, 54*(4), 635–657.
Wei, M., Liao, K. Y. H., Ku, T. Y., & Shaffer, P. A. (2011). Attachment, self-compassion, empathy, and subjective well-being among college students and community adults. *Journal of Personality, 79*(1), 191–221. http://dx.doi.org/10.1111/j.1467-6494.2010.00677.x.
Zenju, H., Nagumo, K., Nozawa, A., Tanaka, H., & Ide, H. (2002). The estimation of unpleasant and pleasant states by nasal thermogram. In *Paper presented at the Forum on Information Technology* (Vol. 3).
Zenju, H., Nozawa, A., Tanaka, H., & Ide, H. (2004). Estimation of unpleasant and pleasant states by nasal thermogram. *IEEJ Transactions on Electronics, Information and Systems, 124*(1), 213–214.