FRONT MATTER: LETTER TO THE EDITOR
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What feels warmer? A red skin versus a red object

Maria V Sanchez-Vives[1,2,*]
[1]Institució Catalana de Recerca i Estudis Avançats; Barcelona, Spain; [2]Institut d'Investigacions Biomèdiques August Pi i Sunyer; Barcelona, Spain

Dear Editor-in-Chief,

This is a reply to the puzzle published in your recent editorial.[1] Blue objects have been reported by Hsin-Ni Ho (Nippon Telegraph and Telephone Corporation, Japan) and her colleagues[2] to feel warmer to the touch than red ones at the same temperature. However, when the hand in contact with an object is colored red or blue -rather than the object being colored red or blue-, the effect is reversed, with red hands making objects feel warmer. I would like to discuss this issue here and propose a possible explanation as well as experiments for testing it.

I live in Spain where numerous light skinned Northerners come for summer vacation. If one walks around the streets of any beach town during the summer evenings it is not unusual to find people whose skin looks painfully reddish. Just seeing that, one can imagine the hot, burning feeling and the painful night ahead with the unbearable touch of the sheets on the skin. Our brains have a consistent association between red skin and warm temperature. The medical description of skin inflammation signs is that of the triad: swelling, redness and warmth. This triad is the consequence of the inflammatory response, a general response to different kind of lesions. Vasodilation is caused by the local release of vasoactive peptides and causes the swelling. Inflammation also causes sensitization of nociceptive fibers, which underlies the well-known feeling of painful touch of an inflamed area, providing a protection of that area from mechanical aggression. At the other extreme of the temperature range, extreme cold causes a vasoconstriction, which reduces the oxygen supply resulting into a bluish color (cyanosis).

Furthermore, skin turns red with hot and blue with cold temperatures, creating obvious associations. The quintessential hot element is fire, is dominated by red, and an iron placed in the fire goes "red hot." Hell is imagined as red and hot and even the devil is displayed as a red figure. Given that the electromagnetic spectrum goes from the infrared to the ultraviolet, and given the association of red to hot, the other extreme is associated to cold. Indeed, thick ice looks blue.

The strong association between red skin and a warm feeling has been demonstrated in numerous psychophysics experiments. For example, the illumination of the skin with a red beam of laser was perceived as warmer than that of a blue laser light, even when both of them had the same temperature.[3] The same was the case with the perceived temperature of a $-20°C$ stimulus in the hand, which was reported to be hot or cold depending on whether it was presented with a red or blue cue respectively.[4] In my laboratory we use fully immersive virtual reality in order to explore body ownership.[5] Once a virtual body is perceived as own, it can be transformed and therefore the perceptual, cognitive or behavioral consequences can be studied. In one of our experiments,[6] we explored the impact of varying the (virtual) skin color of the area of the arm on the temperature-pain threshold. We observed that when the skin around the pain stimulus was red, the average pain threshold across subjects was significantly lower than when the skin was blue. This effect of the red color only occurred for the red skin, while a red path outside the skin did not have this effect of lowering the pain threshold. So it is not the "seeing red" the one that lowers temperature-pain threshold but seeing the own body part turning red.

The brain is largely devoted to making predictions. Since we have observed that red is associated to fire and hot temperatures, our brain may predict that a red object is going to have a warmer temperature than a blue object. The cause for this is that the prediction and thus the expectation is enough, via top-down mechanisms, to influence the temperature perception. In virtual reality experiments, it was demonstrated that putting the hand inside a virtual oven was perceived as "hot" while sticking the hand into a virtual bucket filled with virtual iced water was perceived as "cold," even when in both cases there was the same room temperature (unpublished results). The brain is not only predicting the temperature but there is as well a "filling in" phenomenon that can fill in the congruent sensory input that is missing while in virtual reality.[7]

The paradox presented here is that blue objects are felt warmer to the touch than red ones at the same temperature. However, when the hand in contact with an object is colored red or blue,[2] the effect is reversed, such that red hands feel the objects warmer. The solution that I propose to this paradox is the following:

The skin color is going to determine the temperature perceived, and this is supported by the literature presented above.[3,4,6] Why then touching a blue

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*Correspondence to: Maria V Sanchez-Vives; Email: sanchez.vives@gmail.com

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object feels warmer than touching a red one? I propose 2 testable explanations:

1. The color-contrast explanation: while getting near a blue object, or rather, when in a blue surround, a light skin in contrast looks more reddish. Given that the skin color is the primary determinant of the perceived temperature, a reddish looking hand would perceive warmer temperatures, and thus blue objects would feel warmer. On the other hand, when near a red object, or when in a red surround, the hand will look less reddish and thus the perceived temperature will be cooler for red than for blue objects.
2. The prediction-contrast bias: While touching a red object, the prediction is that it is hot. The contrast between the prediction and the actual temperature may have a reverse effect of feeling it colder than expected.

Both of them, explanation 1 and 2, could interact and add up, since they both go in the same direction. These explanations are amenable of experimental testing and immersive virtual environments would provide a flexible frame for it. In short, an "owned" virtual hand[5] co-located with the real hand (but of which we have a control of the color) could touch virtual objects of red *vs.* blue color. Each time an object is touched the subject should report the perceived temperature in a scale ranging from cold to hot (1 to 10). Red and blue objects could be randomly presented interspersed with objects of other colors acting as controls. A factor to consider would be the size of the object, since I would hypothesize that the larger the object, the larger the surround effect and thus the color contrast effect on the hand. In this design, both explanations would be interacting. However, we could design an experiment to test specifically for the "prediction-contrast bias." For this, we would need to eliminate the hand color factor. This could be achieved by making the hand dark – thus eliminating color contrast phenomena – or by touching the object with the hand out of view. In this case, the subjective perception of temperature could be independently attributed to the color of the object and not to its influence on the perceived hand color. Of course this could be combined with a controlled variation of the touched object's temperature making design and data analysis more complex, but probably providing richer results.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

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