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MEASURING OUR OWN TEMPERATURE SCALE(S). FROM THERMAL SENSATIONS TO THERMAL CONCEPTS

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Research has suggested that some characteristics of misconceptions are explained by the way perception works. In this study, we measured thermal perception qualitatively and quantitatively as well as the relationship of these measurements with the temperature scale. To perform this experiment, we developed a novel device, which generates a thermal gradient. Participants had to slide one index finger along the thermal gradient. They were asked to indicate where they perceived a change of sensation and to estimate the temperature. Perceived temperatures were congruent, whereas the spread of estimated temperatures was significantly higher. This suggests the existence of a common perceptual-qualitative scale and an agreement in how it is reported, but also a lack of an appropriate representation of the temperature variable. The presence of these specific dfficulties in learning should be considered by teachers in science. In this sense, teaching staff should deepen their knowledge of the physiological and perceptual bases of misconceptions to better tackle the learning difficulties of their students.

Keywords: Conceptual Understanding, Misconceptions, Learning and Neuroscience

INTRODUCTION AND THEORETICAL FRAMEWORK

Alternatives conceptions are universal. They are found in people around the world regardless their age, education, gender and cultural background (Abrahams, Homer, Sharpe, & Zhou, 2015). Moreover, they seem very persistent and resistant to change (Chiappetta & Koballa, 2014). These characteristics suggest that misconceptions have a common root. In this sense, some research has suggested that these characteristics are explained by the way our nervous system works (Vosniadou, 1994). Recently, it was proposed that the ambiguity of sensory signals influences the development of alternative conceptions (Ezquerra & Ezquerra-Romano, 2018; Kubricht, Holyoak, & Lu, 2017).

Our thermosensory system does not work like a precise sensor which linearly measures a unique variable. Thermosensations not only depends on the temperature of objects, but other factors such as the material's conductivity also contribute to the experience of thermal sensations (Ezquerra-Romano, Ezquerra, & Agen, 2019). From a neurophysiological perspective, our thermosensory system acquires information thanks to a family of thermosensors which have large, overlapping and non-linear response ranges (Ezquerra-Romano & Ezquerra, 2017). From a perceptual perspective, the perception of temperature emerges from the synergistic interactions between homeostatic nuclei in the brainstem, the hypothalamus, the cingulate cortex, the anterior cingulate cortex and the orbitofrontal cortex (Craig, 2002). From a declarative perspective, we categorise thermal experiences in two wide ranges, cold and hot, which can be subdivided further with different terms (e.g. cool) and adverbs (e.g. very) (Green, Roman, Schoen, & Collins, 2008). The boundaries between these subdivisions are blurry and overlapping. In summary, our thermosensory system does not work like a thermometer. However, from a conceptual perspective, in Physics, temperature is defined as a quantity on a numeric, continuous scale with 0 K (- 273.15º C) as a starting point.

RESEARCH METHOD AND DESIGN

In this study, we investigated the seemingly mismatch between these scales. We measured thermal perception qualitatively and quantitatively as well as the relationship of these measurements with the temperature scale (the Celsius scale). For this, participants had to slide one index finger along a metal bar with a thermal gradient. They were asked to indicate where they perceived a change of sensation. A variation of the Labeled Magnitude Scale (LMS) as developed by Green et al. (2008) was used to label the thermal changes. LMS divides the thermal innocuous range into an ordinal scale: Very Cold (VC), Cold (C), neutral (N), hot (H) and Very Hot (VH). In this study, painfully hot (P) was also included. The positions indicated by the subjects were used to determine the *'perceptual change point'* (e.g. from VC to C). After reporting the change, subjects were asked to estimate the temperature at the location where they had noticed the change of sensation. This numerical value (degrees Celsius, ºC) was called *'estimated numerical value'*.

To perform this experiment, we developed a novel device (Spanish Patent No. 202030815, 2020). The device generates a thermal gradient (10-50 ºC) on a metal bar with Peltier modules. A tactile sensor tracks the position of the finger. The thermal gradient and tactile sensor are adjusted to establish a one-to-one correspondence between the position and the temperature. During the experiment, the experimenter noted down the sensation reported by the subject. Custom-written code and Arduino were used to build the device and collect the data.

RESULTS

Pilot testing was performed on a small sample size (n = 8) due to the restrictions imposed by the pandemic. *Figure 1A* shows the 'perceptual change points' (e.g. from VC to C) (X axis) against the temperature measured by the device at the points where people stopped sliding their finger (Y axis). The standard deviation is between 1.5-4.0 for the different 'perceptual change points'. Participants responses were congruent when they determined the 'perceptual change points', which suggests that their thermal sensation is similar. It seems that there is a common perceptual-qualitative scale which is expressed similarly between people.

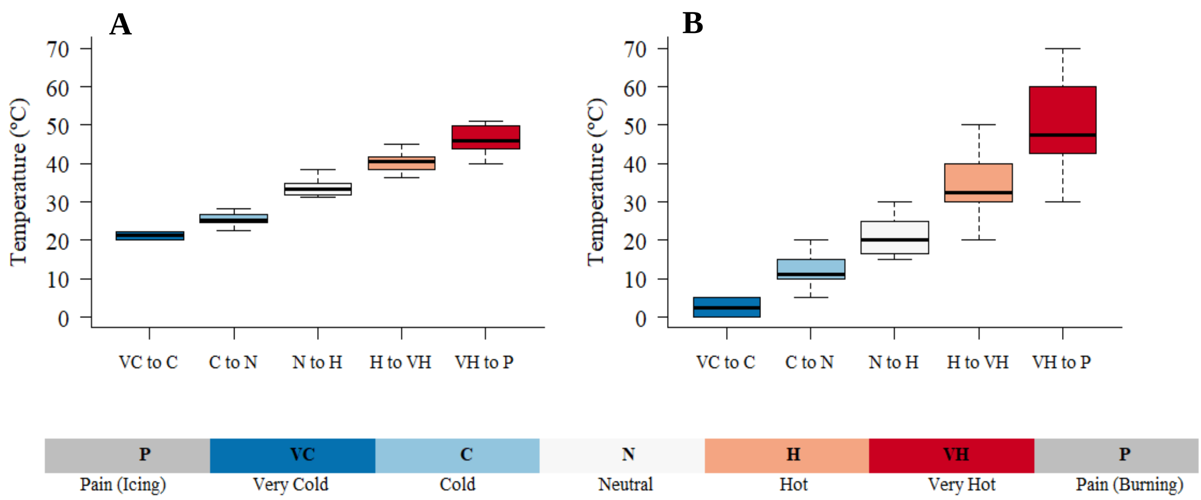

Figure 1. (A) Temperatures registered by the device (left) and (B) 'estimated numerical values' reported by participants (right) against the 'perceptual change points'.

Figure 1B shows the 'perceptual change points' (from VC to C; from C to N) (X axis) against the 'estimated numerical values' reported by participants (Y axis). The standard deviation is higher for these estimated values 3.5–14.0 than for the perceptual observations (Figure 1A).

The temperatures from the perceptual-qualitative scale and the estimated ones have a significantly different dispersion ($F(7,7)$, $p < .05$) in the hot range. In other words, the responses in the estimated scale are much more spread. Moreover, in the cold range, the estimations are significantly lower ($t(14)$, $p < .05$) than the perceived temperatures as measured by our device.

DISCUSSION AND CONCLUSIONS

Our results show that people's thermal sensations are congruent. This suggests the existence of a common perceptual-qualitative scale and an agreement in how it is reported. However, the numeric estimations follow a very different pattern. On the one hand, the estimations are more separated in the cold range (the intervals are not homogenous). On the other hand, the spread increases with temperature. This suggests there is an uncertainty of the thermosensory signals and how these are expressed. People identify the 'perceptual change points', recognise the physical quantity temperature and its units, but they do not seem to correctly estimate their values. This means that they lack an appropriate representation of this variable. This is in line with the hypothesis that the ambiguity of the sensory signals is a contributing factor in the development of misconceptions (Ezquerra & Ezquerra-Romano, 2018; Kubricht et al., 2017).

Based on our results, it seems that the estimation of temperature is a product of the learning process. Therefore, we propose that teachers should develop activities for students to connect the real temperature of objects with their sensations. Finally, the presence of these specific difficulties in learning should be considered by teachers in science. In this sense, teaching staff should deepen their knowledge of the physiological and perceptual bases of misconceptions to better understand and tackle the learning difficulties of their students (Ezquerra & Ezquerra-Romano, 2019).

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