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Left caloric vestibular stimulation as a tool to reveal implicit and explicit parameters of body representation

A. Sedda [a,*], D. Tonin [b], G. Salvato [c,d,e], M. Gandola [c,d], G. Bottini [c,d,e]

[a] Psychology, School of Life Sciences, Heriot-Watt University, Edinburgh, United Kingdom
[b] School of Psychology, University of East Anglia, Norwich, United Kingdom
[c] Department of Brain and Behavioral Sciences, University of Pavia, Pavia, Italy
[d] NeuroMi, Milan Center for Neuroscience, Milano, Italy
[e] Cognitive Neuropsychology Center, Niguarda Ca' Granda Hospital, Milan, Italy

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ABSTRACT

Homeostatic parameters, such as temperature, are related to body representation. In this study, we measured whether caloric vestibular stimulation (CVS) alters body temperature and tactile processing, and if in the direction predicted by a holistic body matrix representation.

Skin temperature and tactile two-point discrimination (TPD) acuity were measured for both arms before, immediately after and with a delay from CVS. Participants were also administered a personality questionnaire and an anxiety inventory to rule out confounding factors. Two control experiments were planned to exclude casual variations.

Our results show that temperature drops significantly in both arms after CVS. CVS also induces a bilateral improvement in tactile acuity (even though not immediately after but in the delayed condition). Finally, these effects are not due to learning, as demonstrated by the control experiment.

In summary, our results suggest that vestibular stimulation updates body representation, supporting the evidence in favor of a body matrix.

1. Introduction

Since the seminal work of Head & Holmes (1911), the concept of body representation has been introduced to convey the idea that motor, sensory and semantic information related to our bodies is represented in the brain (Holmes & Spence, 2004). Typically, body representations are classified in two opposing but intercommunicating categories: a dynamic representation of body parts in space, continuously updated during movement, named body schema, and a more stable representation referring to a semantic description of the body, named body image (de Vignemont, 2010). While representations of the body were initially described as static and resistant to changes (Berlucchi & Aglioti, 1997, 2010), recent studies effectively demonstrate the plasticity of these cognitive abilities. For instance, our body representation is susceptible to the loss of movement abilities (Fiori et al., 2013, 2014) and to the loss of limbs (Andre, Paysant, Martinet, Beis, & Le Chapelain, 2001). Similarly, illusory manipulations in healthy subjects are effective in distorting body ownership (Moseley et al., 2008).

* Corresponding author.
E-mail address: a.sedda@hw.ac.uk (A. Sedda).

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More recently, the idea of a body matrix incorporating different signals from psychological to homeostatic ones has also been proposed (Moseley, Gallace, & Spence, 2012). According to this view, a discrete contraposition between representations of the body is not necessary to explain experimental and clinical data. Differently, the authors propose a more holistic representation, composed by information maintained by multisensory and homeostatic networks in the brain and differently activated and extremely plastic depending on the relationship with the environment (Moseley et al., 2012).

Independently from the theoretical approach, the contribution of motor, visual, auditory and proprioceptive information throughout multisensory systems in the development and maintenance of the body representation is out of doubt (Berlucchi & Aglioti, 2010; Holmes & Spence, 2004; Moseley et al., 2012). However, there still is a strong debate on the role of the vestibular system (Ferrè, Day, Bottini, & Haggard, 2013; Ferrè, Vagnoni, & Haggard, 2013; Lopez, Schreyer, Preuss, & Mast, 2012). This system's pivotal role in controlling posture and balance, the harmonic relations between the body segments and in coding body rotations and orientations are well known. Thus, it would not be surprising that vestibular information is taken into account also into a body matrix, updated and modified accordingly to environmental changes (Moseley et al., 2012).

Interestingly, Lopez et al. (2012) have recently demonstrated that when a stimulation of the vestibular system occurs, the perception of the body segments is immediately modified. In detail, the authors demonstrate that during perturbation of the vestibular system the hand size representation is modified, being perceived as elongated and larger than in normal conditions (Lopez et al., 2012). This study is the first one directly affirming a causal relationship between the vestibular system and a dynamic representation of the body, even though previous studies already demonstrated a correlation between sensory components. For instance, Ferrè, Sedda, Gandola, & Bottini (2011) showed that when caloric vestibular stimulation is delivered to subjects while they perform a tactile detection task, the perceptual threshold is modified in a multisensory fashion. As tactile signals are known to contribute to body representation (Medina & Coslett, 2010), there it follows the indirect assumption in favor of an influence of vestibular signals on body representation.

In the above-mentioned studies, one common feature is that tasks employed require an answer by the subjects. Being a judgment on the metric of body parts (Lopez et al., 2012) or a detection of a signal (Ferrè et al., 2011), the subject is always asked to "participate actively" in the task. However, a crucial feature of the body representation interpreted in terms of a holistic representation such as the body matrix (Moseley et al., 2012) is its ability to operate in an automatic fashion and independently from direct control of the subjects (Berlucchi & Aglioti, 2010; de Vignemont, 2010). Thus, to further explore the modulation of the vestibular system on body representation, the assessment of multiple parameters in conjunction including homeostatic ones is desirable.

Recently, an experiment showed that homeostatic changes occur when limb ownership is modified (Moseley et al., 2008). In the rubber hand illusion (RHI), multisensory visual and tactile information modulation allows creation of the illusion in the subjects that a rubber hand is incorporated in their body (Botvinick & Cohen, 1998). Importantly, not only explicit parameters such as subjects' feelings of ownership are affected, but also body temperature is modulated by this experimental manipulation. In fact, in presence of the RHI, temperature drops for the real hand (Moseley et al., 2012), suggesting that the subjects temporarily dismiss one limb in favor of the incorporation of the fake rubber hand. This RHI experiment demonstrates that homeostasis not only varies accordingly to the exchanges between our body and the environment, but can also be cortically mediated. Changes in body temperature are reported also in illusions involving the entire body (Macauda et al., 2015; Salomon, Lim, Pfeiffer, Gassert, & Blanke, 2013). Similarly to the RHI, a Full Body Illusion (FBI) can be elicited in individuals when temporally synchronous visual and tactile stroking is simultaneously applied to an individual's body and to a virtual body. However, in the RHI decreased temperature is reported in the illusion condition only in the stroked hand. On the other hand, the cooling effect in the FBI is not restricted to the stroked locations (i.e. only the back or only the leg) neither is lateralized (i.e. the effect is present for both the right and the left side of the body) (Salomon et al., 2013). The Authors speculate that the difference between the RHI and the FBI might be due to a coarser resolution of body representation activated by the receptors on the back/leg versus the hand.

In spite of these recent findings, body ownership and illusory modulations of full body representation are highly debated and still very mysterious, as these phenomena play their game at a high cognitive level and might be influenced by different factors. Not by chance, a study exploring temperature changes after vestibular stimulation in patients desiring to amputate their own limbs did not find significant associations between body temperature and feeling of estrangement for body parts (Lenggenhager, Hilti, Palla, Macauda, & Brugger, 2014).

The aim of our study is to further explore if left cold caloric vestibular stimulation (CVS) modulates temperature of the body and whether changes in temperature are paralleled by modifications in other body representation parameters. More in detail, if CVS has a direct effect on the body representation, one should expect a change in temperature and also in tactile acuity, a parameter associated to body representation that requires an active perception by the subject but is a much more basic function than body ownership. This should be induced by the fact that CVS temporarily modifies the body representation and its associated parameters. On the other hand, if a change in temperature is observed without other modifications, one could hypothesize that CVS acts on physiological parameters not necessarily related to the body representation and that effects are diverse at basic and higher associative cognitive functions.