HABEMO: An innovative haptic tool for investigating the bodily representation of mental states in individuals with visual impairments

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Abstract

The embodiment of emotions constitutes a profound aspect of our psychological experience, shaping not only how we express but also how we perceive and understand our feelings. Here, we introduce an innovative haptic tool to explore the relationship between emotional states and bodily reactions, with a focus on its applicability to individuals with visual impairments. Our paradigm is highly intuitive, ensuring accessibility while maintaining accuracy comparable to traditional tasks reliant on visual stimuli. Through motion tracking and a 3D human representation, our system allows to capture in a naturalistic manner where individuals sense affective and cognitive states within their bodies. To validate this method, we conducted two experiments employing both haptic and visual versions of the same task, revealing a compelling alignment between modalities in capturing individuals' internalized manifestations of emotional states.

Our novel haptic paradigm allows the mapping of emotions in the body in an intuitive way, offering a more inclusive and versatile method for exploring how people connect their emotions to their physical experiences. More importantly, the haptic version of our task holds particular promise for investigating how individuals with limited or no visual capability maintain representations of emotional and cognitive states within their bodies. In addition to its profound implications for understanding emotions, this innovative tool holds promise for exploring a wide variety of research questions beyond the realm of affective states, thereby broadening its utility as a versatile instrument for investigating various aspects of human perception, cognition, and embodiment particularly within the context of visual impairment.

Keywords: Touch, Embodiment, Body representation, Visual impairment, Blindness.

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1. Introduction

Emotions are a cornerstone of human life, emerging in response to both external and internal events, carrying a positive or negative character and triggering reactions across the autonomic, cognitive, and perceptive systems (e.g., Cacioppo and Gardner, 1999; Keltner and Lerner, 2010; Izard, 2010). Emotional states are frequently linked with facial expressions, body postures, and gestures, as well as observable physiological reactions like increased perspiration and concealed responses like heartbeat variations (Levenson, 2003; De Gelder et al., 2015) or changes in gastric activity (Porciello et al., 2023). Importantly, alterations occurring in the body during and subsequent to an emotional occurrence enable people to draw conclusions about their surroundings and themselves (Damasio, 2003; Craig, 2008). For example, a racing heart might indicate excitement prior to a concert or anxiety preceding an exam. Similarly, we might detect an elevated heartbeat before publicly asking a question, alerting ourselves in moments of discomfort. This interplay between our emotions and bodily sensations forms a crucial part of our self-awareness (Critchley and Garfinkel, 2017). Remarkably, humans can pinpoint the location within their body where they sense a connection to an emotional state, even when simply reflecting on it rather than actively experiencing it in the moment (De Gelder, 2006).

The emBODY tool was developed to empirically investigate how people experience emotion in their body (Nummenmaa et al., 2014). This online self-assessment tool enables participants to use a mouse to sketch on a human silhouette displayed on a screen, where they feel affective or cognitive states within their body. Findings using this paradigm unveiled bodily maps linked to various emotional categories (Nummenmaa et al., 2014). Since its development, emBODY became a prominent tool to explore the connection between bodily sensations and mental states across diverse contexts and instances of pathological conditions (e.g., Suvilehto et al., 2015; Torregrossa et al., 2019; Sachs et al., 2019; Goldstein et al., 2020; Volynets et al., 2020; Herman et al., 2022), as well as across different cultures (Volynets et al., 2020).

Various adaptations of the task have been formulated and implemented to cater to the specific requirements of acquiring data in particular groups. For example, a pen-and-paper variant of the tool has been used with children as young as six to investigate the developmental trajectory of bodily maps of emotions (Hietanen et al., 2016). This approach allows for exploring connections between bodily responses and emotions in populations that, for various reasons, might lack familiarity or access to technology, such as older individuals. However, the pen-and-paper version of the tool has some limitations as it necessitates precise control over hand movements and motor skills. In an alternate approach, recent studies transformed the visual emBODY tool into a semi-structured interview format, prompting participants to verbally link emotional categories to patterns of physical sensations (Butera et al., 2023; Giraud et al., 2023). However, this experimental design also has limitations, as it does not allow for a fine-grained investigation of bodily responses. Specifically, the standard analysis pipeline for the bodily maps requires a pixelwise investigation, so that the between subjects' average for activation and deactivation is tested against zero (Nummenmaa et al., 2014), which cannot be applied using interviews and is crucial for objectively assessing the spatial distribution of bodily sensations across individuals. Lastly, all the implemented versions of the emBODY tool, so far, rely on the sense of vision to be used or do not provide enough resolution for a pixelwise investigation, making them inaccessible in conditions of low vision or the absence of sight.

The prevailing reliance on visual paradigms in research has resulted in the exclusion of individuals unable to access or interpret visual information, despite their substantial presence in the global population (about 3 %; IAPD Vision Atlas 2020). In the social and affective domain, this exclusion hinders our understanding of how the absence of visual input impacts emotional processing. Indeed, vision aids in detecting potential threats or dangers in the environment, which can trigger fear or anxiety responses. For instance, observing someone's tense body language or an oncoming vehicle prompts immediate emotional reactions related to survival instinct. On the other hand, research on visually impaired individuals allows us to understand the role of non-visual sensory experiences in shaping affective states, such as the emotional relevance of a comforting touch or the aroma of a familiar scent.

To bridge this gap, our study introduces an innovative haptic paradigm specifically designed to investigate the association between emotional and cognitive states and bodily reactions in the context of visual impairment and blindness. Compared to previous methods, our tool does not necessitate vision, precise motor control, or familiarity with technology. At the same time, it guarantees the acquisition of bodily maps that are as accurate as those obtained with the traditional emBODY tool. Through the integration of motion tracking and a 3D human representation, our system allows to capture in a naturalistic manner where individuals sense affective and cognitive states within their bodies. This novel approach aims to provide insights into the bodily experience of populations traditionally underserved by existing methodologies. By focusing on the study of blind individuals, we can significantly deepen our understanding of how sensory experiences influence both affective and cognitive processing associated with bodily sensations.

2. Materials and methods

Participants – Haptic experiment. A total of 42 healthy French native speakers (25 F; mean age 21.9 ± 3.8 years) were enrolled in the study. To participate in the experiment, individuals needed to be over 18 years of age, without any medical history of developmental, neurological, neuromuscular, sleep, or psychiatric disorders, and not regularly using psychotropic medications. All participants provided informed consent and retained the right to withdraw from the study at any point. Before the beginning of the experiment, subjects completed the Positive and Negative Affective Schedule (PANAS; Watson et al., 1988), the State-Trait Anxiety Inventory (STAI-Y2; Spielberger, 1983), and the Toronto Alexithymia Scale (TAS; Bagby et al., 1994) to evaluate their mood, anxiety levels, and alexithymia traits, respectively. The study was carried out following the Declaration of Helsinki and received approval from the local IRB (CEHF: Comité d′éthique ospital-facultaire; Protocol No. B403201628743). Participants received academic credits for their participation in the study.

Experimental setup – Haptic experiment. A gender-neutral 3D mannequin depicting a human body was affixed to a wooden structure that enabled its rotation, showcasing both its frontal and dorsal sides. Positioned on the wooden base of the structure was a tripod bearing a camera, atop which a ring light was attached to regulate luminance (Fig. 1A). A 3D explorable representation of the experimental setup can be found at the following link: https://shorturl.at/oxH68.

Thirty emotional terms were employed in the study, balanced between positive and neutral (n = 16) and negative (n = 14) states, according to valence score (from 1 to 7) reported in Gilet et al., 2012: tenderness (valence = 6.0), love (valence = 5.9), alert (valence = 5.9), calmness (valence = 5.7), attraction (valence = 5.6), joy (valence = 5.6), enthusiasm (valence = 5.5), ecstasy (valence = 5.4), pleasure (valence = 5.3), euphoria

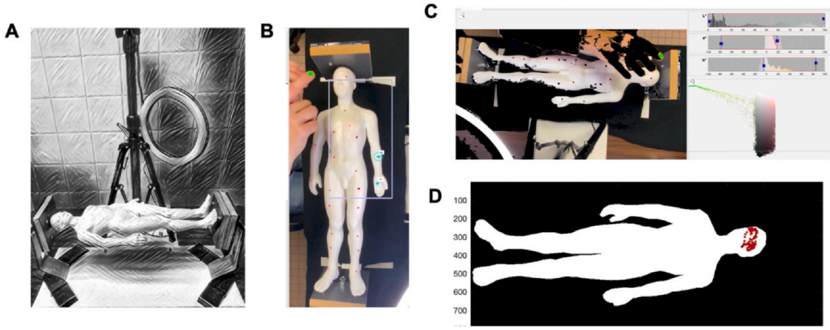

Fig. 1 Experimental setup and preprocessing pipeline. A 3D mannequin representing a genderless human body was mounted on a wood structure and on its floor was installed a tripod holding a camera on top, to which was attached a ring light to control luminance (panel **A**). In panel **B** a depiction of the red markers applied on the mannequin for alignment purposes and the green sticker on the finger of a participant. Color thresholding was applied to then isolate the trajectory of the green sticker (panel **C**), and the final single-subject tracking for one emotion is reported in panel **D**.

(valence = 4.8), amazement (valence = 4.6), exaltation (valence = 4.6), excitement (valence = 4.4), curiosity (valence = 4.3), astonishment (valence = 4.1), nostalgia (valence = 4.0), embarrassment (valence = 3.6), agitation (valence = 3.4), nervousness (valence = 2.9), repulsion (valence = 2.3), anxiety (valence = 2.2), sadness (valence = 2.2), fury (valence = 2.2), panic (valence = 2.2), terror (valence = 2.1), disgust (valence = 2.1), wrath (valence = 2.0), horror (valence = 1.6), aggressiveness (valence = 1.5) and despair (valence = 1.5).

Experimental procedure – Haptic experiment. All participants had no previous visual information of the experimental setup and were blindfolded with a professional eyeshade (Goalfix Eclipse) for the entire duration of testing and before entering the experiment room. They were seated comfortably in front of a table with the mannequin placed on it, allowing easy and unrestricted interactions. Prior to the main task, participants were requested to identify eight organs and body parts on the mannequin (e.g., heart, liver, elbows, calves) to ensure their familiarity with the body figure. A round green sticker was applied to the index fingernail of their dominant hand to track participants' movement on the mannequin (Fig. 1B). Throughout the experiment, participants were free to explore the mannequin using both hands but were required to respond using only the finger bearing the sticker. During the core task, participants had to indicate which parts of the body they typically felt activated when feeling a particular emotion. Specifically, for each trial, the instructions were: "*Think about when you feel [emotion], mark with your finger as if it were to color all the areas of the body where you perceive an increase in their activity*." Subjects were prompted to reflect on their personal experience and report their own bodily perceptions. In each trial, recordings of subjects' responses were carried out by a high-resolution camera (1080p, 60fps). The camera was remotely activated by one of the experimenters once the participant's hands left the wooden surface. Filming ceased once the volunteer's hands touched the wooden platform again. As a result, brief videos were obtained for each participant and emotion, providing the tracking of participants' hand on the body mannequin. The sequence of trials (i.e., emotions) was randomized across participants. An example of the execution of the task can be found at https://osf.io/e8gr6/?view_only=86bdca872aca4f2588f31f8ed07de333.

Analysis - Haptic experiment. As the camera employed for tracking the participants' hand movements was detachable, the initial phase of generating group-level emotional bodily maps involved aligning the videos from each trial and participant to a shared body silhouette. This process helped to compensate for possible misalignments between experimental sessions. For this purpose, we initially marked 24 red dots on the mannequin and recorded a short video of its front and back. The first frame of this template video was imported into MATLAB and used as a reference (i.e., fixed image) in a semi-automated alignment procedure. To carry out the alignment, the initial frame of each experimental session's first video (i.e., moving image) was also imported into MATLAB, and the *cpselect* function was employed to manually identify the coordinates of the 24 markers on both the fixed and moving images, corresponding to the red dots. Subsequently, a projective geometric transformation was fitted to the pairs of control point coordinates using the *fitgeotrans* function. Lastly, each video frame of the trial was aligned to the template frame by applying the computed geometric transformation with the *imwarp* function (linear interpolation) and using the grid and dimension of the template video as a reference frame. Given that the camera remained stationary during an experimental session, the identical geometric transformation was applied to all trials from the same session (encompassing the complete data collection for one participant). Although variations in the procedure might exist, the alignment stage is a shared component in other versions of the emBODY task, including the paper-and-pencil approach (Hietanen et al., 2016).

The subsequent step to obtain group-level bodily maps involved segmenting the green marker on the index finger's nail of the participant's dominant hand and reconstructing its trajectory during the haptic exploration of the mannequin (Fig. 1B–D). To this aim, we imported the video of each trial into MATLAB once it had been aligned to the common template. Then, each video frame was converted from the RGB to the CIE 1976 L*a*b* color space using the *rgb2lab* function. An optimal color threshold was manually defined in the L*a*b* space by visually inspecting the segmented version of the marker and interactively adjusting the values (Fig. 1C). The L*a*b* threshold values were subsequently applied to all the video frames (1920 *1080px). Despite setting these thresholds individually for each participant, they exhibited considerable similarity due to consistent luminance conditions across experimental sessions, as well as the use of the same camera throughout the data collection (luminance [min max] = [0100]; a = [−77.7 ± 3.0; −12.6 ± 5.3]; b = [−27.3 ± 6.8; 79.7 ± 4.2]). The thresholding procedure generated a binary mask for each frame, in which pixels with value 1 (i.e., “true”) denoted the marker on the participant’s fingertip, while those with value 0 (i.e., “false”) represented the remaining part of the image. To reconstruct the trajectory of the segmented marker over time, we first used the *bwpropfilt* function to retain only the largest connected region surviving the color threshold. This procedure is to exclude false positive pixels passing the color threshold. Then, we addressed potential holes in the segmented region with the *imfill* function and estimated the centroid coordinates of the resulting cluster of pixels using the *regionprops* function. In line with previous emBODY implementations (Nummenmaa et al., 2014), the trajectory of the marker was masked with a silhouette of the mannequin, which was drawn by one of the experimenters using the drawpolygon routine and the template frame as reference.

Another typical step in the emBODY pipeline is smoothing the single-participant bodily maps to account for between-participant variability in the drawing. To implement this procedure in the haptic experiment, we applied a 2D Gaussian filter with $\sigma = 10$ pixels and max amplitude = 1 on each coordinate derived from the segmentation phase. Because neighboring Gaussian filters were combined into a single bodily map, the highest observed value across pixels was contingent on the duration the participant spent on a specific body area (as in the case of the color intensity in the drawing version of the emBODY task). To uniform data coming from different volunteers, we thus divided the pixel values by the maximum of the bodily map within each participant. The single participant smoothed bodily maps of emotion were visually inspected, and the quality of the procedure was evaluated by comparing the marker trajectories with the original videos. Lastly, group-level bodily maps of emotion were obtained by computing for each pixel the between-participant average.

Participants - Visual experiment. A sample of 65 healthy French-speaking individuals (46 F; mean age 21.7 ± 1.7 years) completed an online version of the haptic task. All participants granted permission to handle their personal data in adherence to the EU GDPR 679/2016 regulation. The study was approved by the local IRB (CEHF: Comité d'éthique hospitalo-facultaire; Protocol No. B403201628743). Volunteers have been recruited through local university channels, social media, and word-of-mouth. Prior to the start of the study, participants received a comprehensive briefing on the experimental processes. Monetary compensation was not provided to any participant, and each individual retained the right to interrupt the experiment at any point.

Experimental procedure - Visual experiment. An online version of the same questionnaires as those used by the participants of the haptic experiment were used, balanced for the number of trials to equate cognitive load of participants. Each participant was asked to answer a total of ten trials, coloring ten bodily maps of emotion. Clicking on the link directed participants to the central webpage housing our questionnaire, which was structured into four segments preceding the experimental task: (A) Informed Consent and Personal Data Collection; (B) PANAS; (C) STAI-Y2; (D) TAS. After completing the questionnaires, subjects were presented with an example of the task and the associated instructions through a video. Notably, the same approach used in the haptic experiment's execution was adapted for the online study. Participants were required to color with a red circled brush body regions where they perceived increased activity associated with the same emotions used in the haptic version. The silhouette employed in the visual version was derived by photographing and then cutting out the outline of the physical mannequin in its front and rear parts (Fig. 2). Participants could erase their drawings in case of errors, but once their response was confirmed, they could not revise their answers.

Analysis - Visual experiment. The processing of bodily maps obtained from the visual experiment follows the steps recommended by Nummenmaa and colleagues (2014). Thus, for each participant and emotion, we first converted the obtained images to the CIE 1976 L*a*b* color space (*rgb2lab*) and then isolated colored areas by thresholding the images based on the red color participants used to provide their answers. As for the haptic experiment, we masked participants' responses with a

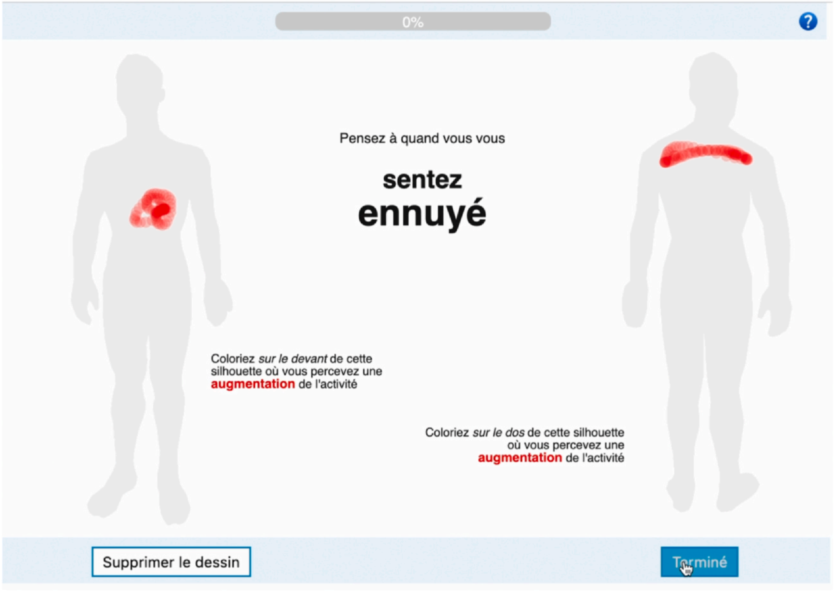

Fig. 2 The example provided to participants before performing the visual experiment. The instruction was, as in the haptic version of the task, "Think about when you feel [emotion], color all the areas of the body where you perceive an increase in their activity". On the right part of the screen participants had the anterior part of the silhouette to fill, while on the left side the back section.

silhouette of the body and applied a smoothing procedure using a Gaussian filter with $\sigma = 2$ pixels. The reason for choosing a σ lower than the one employed in the haptic experiment is justified by the lower resolution of the images obtained from the online experiment (640 *241px) as compared with the videos recorded in the laboratory for the haptic task. For each emotion, single-participant bodily maps were then normalized to have peak intensity equal to one and aggregated across individuals by computing the average in each pixel.

Measuring the similarity between haptic and visual bodily maps of emotion. To validate the haptic version of bodily maps of emotion, we correlated group-level bodily maps obtained from the visual and haptic experiments using Pearson's correlation coefficient. Prior to assessing the similarity between modalities, we coregistered data obtained from the haptic experiment with those coming from the visual one using a semi-automated procedure similar to what described above. In brief, a set of points were identified on the visual and haptic silhouette of the mannequin and a projective transformation was employed to estimate the transformation needed to align the two. The computed transformation was applied to all group-level bodily maps of emotion of the visual modality. Then, group-level bodily maps were correlated between experiments using Pearson's coefficient and the significance of association was established ($p < 0.05$). Further, we tested the correspondence between the emotion-by-emotion representational dissimilarity matrices (RDM) derived from the two tasks (Kriegeskorte et al., 2008). To do this, we computed the pairwise distance (Pearson correlation distance) between all possible pairings of bodily maps within experiment. After having repeated such a procedure for the two experiments, we correlated the obtained RDMs using Kendall's Tau correlation coefficient to measure how much the relationships between emotions in the space of bodily sensations is affected by the experiment modality.

3. Results

We first confirmed that the two samples enrolled in the visual and the haptic experiment did not differ in age ($p = 0.71$) and were balanced between the two genders ($p = 0.23$). Moreover, there was no significant difference in their positive mood levels (PANAS positive: mean visual sample = 27.0 ± 6.5; mean haptic sample = 28.1 ± 6.2), while we found less negative mood in participants performing the haptic experiment (PANAS negative: $p = 0.046$; mean visual sample = 14.7 ± 4.2; mean haptic sample = 13.0 ± 3.2). Anxiety levels exhibited no significant differences between the two groups (STAI: mean visual sample = 47.7 ± 9.6; mean haptic sample = 46.4 ± 9.8; $p > 0.05$), and there were no substantial distinctions in terms of alexithymia traits (TAS: mean visual sample = 49.0 ± 10.8; mean haptic sample = 45.0 ± 10.8; $p > 0.05$).

When correlating the group-level bodily maps of emotion obtained from the two experiments, we found that for all our emotion categories, there was a significant correlation between modalities (Table 1; Fig. 3 and Supplementary Figures 1–4; all rhos ranged from 0.73 to 0.22; all $p < 0.01$). Specifically, we observed a rho value equal to or higher than 0.7 for the emotions of amazement, love, nostalgia, and wrath (Fig. 3), and equal or above 0.6 for the states of alert, anxiety, astonishment, disgust, euphoria, exaltation, horror, repulsion, sadness, tenderness and terror (Supplementary Figures 1–4). Overall, for 19 emotional states we observed a strong correlation between the visual and haptic modalities, while for other nine a

Table 1 Correlation between group-level bodily maps of emotion obtained from the visual and haptic experiment for all our emotion categories.

Emotion	rho	p-value
Aggressiveness	0.43	<0.01
Agitation	0.22	<0.01
Alert	0.61	<0.01
Amazement	0.74	<0.01
Anxiety	0.66	<0.01
Astonishment	0.65	<0.01
Attraction	0.56	<0.01
Calmness	0.29	<0.01
Curiosity	0.41	<0.01
Despair	0.59	<0.01
Disgust	0.64	<0.01
Ecstasy	0.41	<0.01
Embarrassment	0.48	<0.01
Enthusiasm	0.43	<0.01
Euphoria	0.68	<0.01
Exaltation	0.68	<0.01
Excitement	0.43	<0.01
Fury	0.49	<0.01
Horror	0.60	<0.01
Joy	0.57	<0.01
Love	0.70	<0.01
Nervousness	0.34	<0.01
Nostalgia	0.70	<0.01

Table 1 Correlation between group-level bodily maps of emotion obtained from the visual and haptic experiment for all our emotion categories. (*cont'd*)

Emotion	rho	p-value
Panic	0.49	<0.01
Pleasure	0.57	<0.01
Repulsion	0.66	<0.01
Sadness	0.67	<0.01
Tenderness	0.62	<0.01
Terror	0.62	<0.01
Wrath	0.73	<0.01

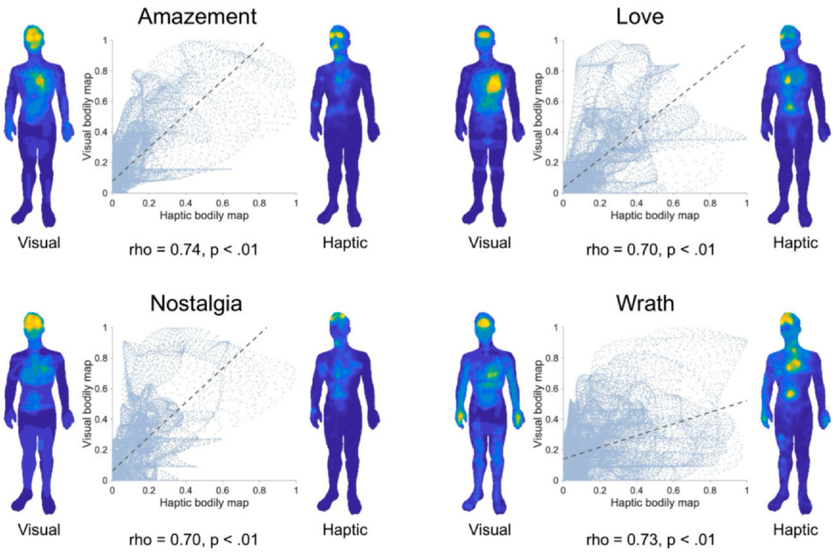

Fig. 3 The figure depicts the comparison between bodily maps of emotion obtained from the visual experiment (on the left of the scatter plots) and from the haptic one (on the right of the scatter plots) for the affective categories showing a correlation value equal to (love and nostalgia) or higher than 0.70 (amazement and wrath). Scatter plots report for each emotion the association between the haptic and the visual bodily map, where each dot represents a pixel in the bodily map.

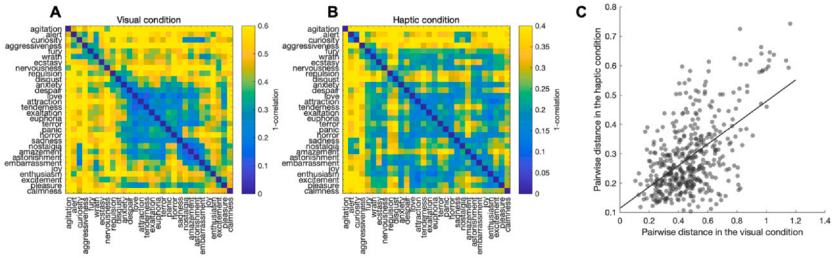

Fig. 4 The emotion-by-emotion RDM obtained from the visual experiment (panel **A**) and from the haptic modality (panel **B**). In each RDM, we express the dissimilarity between emotion pairings computed on the group-average bodily maps. Blueish colors indicate lower dissimilarity. Emotions are arranged based on their relative distances. Panel **C** shows the correlation between the visual and haptic RDMs (Kendall's Tau = 0.30, $p < 0.001$). Each dot in the chart represents an emotion pairing.

moderate one, showing a high level of similarity across the two conditions. We also found few emotional states for which the correlation value was between 0.22 and 0.34, showing a less strong association between the haptic and visual modality (i.e., agitation: rho = 0.22, calmness: rho = 0.29, and nervousness: rho = 0.34; Supplementary Figures 1–4).

Also, we tested the correspondence between the emotion-by-emotion RDMs derived from the two experiments. We found that the RDM obtained from the visual experiment was strongly correlated with the one retrieved from the haptic modality, with a statistically significant Kendall's Tau of 0.30 ($p < 0.001$; Fig. 4). This indicates that the arrangement of emotions in the space determined by bodily sensations is highly similar between modalities.

4. Discussion

In the present study, we developed a novel behavioral paradigm aimed at mapping emotions in the body, particularly targeting individuals with visual impairment or blindness, as well as those with limited hand dexterity or technological familiarity. Studying blind individuals is particularly crucial as it offers unique insights into how the absence of visual input shapes emotional processing and the role of non-visual sensory experiences in affective states, contributing to a more comprehensive understanding of human emotion and cognition. To validate this innovative method, we conducted both haptic and visual versions of the same task to assess the consistency of bodily representation of emotions across different modalities. Our findings revealed a strong correlation between the haptic and visual modalities in how they capture individuals' representations of emotional states in their bodies. Notably, the haptic version of our task allows for a naturalistic evaluation of bodily maps, opening avenues for future investigations into how individuals with limited or no visual capability perceive a range of cognitive and affective states in the body (Lettieri et al., 2024).

Exploring emotional experiences has consistently posed challenges to researchers, primarily stemming from the inherent difficulty of gaining insight into the inner thoughts and feelings of individuals (e.g., Izard, 2009). Nevertheless, emotions are integral to human experience and behavior, influencing how we perceive, interact with, and navigate the world around us (Plutchik, 1994). The ability to identify and comprehend emotions holds the potential to yield significant benefits, including heightened self-awareness, the cultivation of more positive relationships, improved decision-making, and an overall elevation in the quality of life (Schutte et al., 2002; Sánchez-Álvarez et al., 2016; Fernández-Berrocal and Extremera, 2016).

The predominant focus of previous research in the affective domain has been centered on the examination of emotions through static stimuli, such as images, and in some instances, brief video clips spanning only a few seconds (e.g., Blair et al., 2007; Codispoti et al., 2008). Nevertheless, this conventional approach may have certain limitations when it comes to fully capturing the intricate tapestry of emotional experiences that individuals encounter in their everyday existence. The reliance of this approach on visual stimuli precludes the inclusion of blind and visually impaired individuals, thereby neglecting a substantial segment of the population and potentially constraining the applicability of findings across diverse sensory modalities and experiences. The development of our innovative haptic task holds significant implications, particularly for populations such as blind and visually impaired individuals who have been historically excluded from conventional studies reliant on visual stimuli. Indeed, a comprehensive understanding of the pivotal role that each sense plays in shaping our experiences and behaviors is imperative before drawing conclusions about the consequences of its absence.

Here, we found that the haptic and visual versions of the same task are highly correlated among themselves for the majority of the emotional states employed in the study, highlighting the validity of using the tactile channel to study bodily emotions. We also observed some peculiarities for the two modalities, as for instance, we found emotional states for which the correlation between the two tasks was lower compared to most of the other emotions tested (e.g., nervousness; Supplementary Figure 3). In this case, upon visual inspection (Fig. 3), the visual modality seems to have more coherence in responses compared to the haptic one, even if in both bodily maps, the region of the stomach is the common area highlighted by individuals. Therefore, results coming from the two modalities are globally aligned, with some peculiarities observed for each of them specifically. This might be due to individuals' personal characteristics and propensity to answer more confidentially using the haptic or the visual sensory channel. In this regard, we recruited two independent groups for the execution of the tasks, to avoid possible influences and cross-talks between the two conditions. Indeed, a response given after replying to the same question using a different modality might be attenuated and, therefore, not fully reliable. Future studies might investigate the role of personal characteristics in reporting affective experience across sensory channels.

Moreover, our paradigm can be easily adapted for a naturalistic investigation using neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), by employing an MRI-compatible camera. This approach would therefore allow for the concurrent examination of brain activity and bodily responses in individuals with visual impairments. By investigating the neural substrates of bodily maps, future studies could uncover the intricate interplay between sensory input, emotional processing, and higher-order cognitive functions, further enriching our understanding of plasticity mechanisms involved in sensory deprivation.

In addition to its profound implications for exploring the fundamental role the body plays in the representation of emotions, our innovative tool holds promise for exploring a wide variety of research questions beyond the realm of affective states. For instance, investigations into how the body schema of individuals might change after experiencing some kind of illness could benefit from the naturalistic evaluation enabled by our haptic modality. Importantly, within the context of visual impairment, this tool opens new avenues for examining the impact of visual deficits on body representation and the associated feelings across various experiences.

In conclusion, by broadening its utility across various domains of research including the exploration of cognitive and affective states in special populations, this innovative paradigm offers valuable insights into the complexities of human experience and behavior, particularly in populations facing sensory deprivation.

Author contributions

Giada Lettieri: Conceptualization, Data curation, Formal analysis, Visualization, Writing - Original Draft Preparation, Writing - Review & Editing; Roberta Pia Calce: Data curation, Writing - Review & Editing; Olivier Collignon: Conceptualization, Writing - Review & Editing, Supervision.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/bs.pbr.2025.02.001.

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