Short Communication

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# Mapping emotions on the body

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**Abstract:** Emotions are allostatic processes that transform the relationship between the environment and the desired bodily states into behaviour supporting homeostasis and well-being. Central emotion circuits are thus tightly coupled with the visceral signaling pathways and the autonomic nervous system (ANS). Although ANS activity patterns are not always emotion-specific, self-reported bodily sensations and pattern recognition analysis of functional magnetic resonance imaging data suggest discrete bodily and neural basis of emotions. The advent of total-body positron emission tomography (PET) systems allows simultaneous measurement of the central and peripheral axis of the emotional response. This provides a unique opportunity for quantifying the systems-level biology of the human emotion circuits.

**Keywords:** body; emotion; positron emission tomography; somatosensation.

## Mapping emotions on the body

Emotions prepare the organism for action via allostasis by transforming the relationship between the environment and the desired bodily states into behaviour that supports homeostasis and well-being. Higher mental processes and their neural bases are also tightly linked with the homeostatic control of the body, and the brain responds continuously to the afferent visceral signals conveyed by the spinal and cranial nerves [1]. Experience of self and emotions also emerge from the central representation of the body's physiological state [2]. The insular cortex represents autonomic responses and changes in visceral state and together with amygdala medial frontal cortex encodes the subjective emotional feelings, thus serving as the key hub for generating the subjective experience of emotion [3]. Somatosensory cortices are also consistently activated during emotional perception, and statistical pattern recognition studies have confirmed that individual's current emotional state can be reliably "decoded" based on the haemodynamic activity in the somatosensory cortex [4].

## Self-reports capture discrete emotion categories in the body

Different emotions (such as fear and anger) manage responses to different survival challenges, hence it has been proposed that distinct emotions are subserved by distinguishable neuroanatomical circuits modulating the activity of different peripheral physiological responses [5]. Although distinct emotions are supported by discernible neural circuits and emotional expressions are discrete [6] it remains unresolved whether low-dimensional autonomic measurements are sufficient for distinguishing specific emotions from each other [7, 8]. This casts doubts on the specificity of the allostatic responses generated by emotions and raises questions regarding the specificity of the autonomic changes associated with different emotions. Yet a likely reason for the low specificity of ANS activity across emotions is simply a methodological artefact. Most studies on bodily basis of emotions focus on a narrow set of functions under autonomic control, such as heart and breathing rates, blood pressure and electrodermal responses [7, 8], which are strongly correlated. It is thus not surprising that differentiation cannot be established for autonomic signals if high-dimensional autonomic target signals are not measured in the first place.

Recently we have addressed this issue using self-reports (Figure 1A). Instead of direct measurement of low-dimensional autonomic changes, we simply asked subjects to indicate in a blank human body template whereabouts they experience changes during emotions [9]. The results consistently show that different emotions are associated with statistically discernible "feeling fingerprints" and that these patterns emerge when subjects are asked to

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recall their past emotional episodes or when emotions are induced with videos or narratives and subjects are simply asked to indicate whereabouts in their body they currently feel something. Although these measurements are physiologically unspecific and constitute of self-reports, they consistently show that the phenomenological experience of different emotions is discrete in the body. These bodily maps of emotions are culturally invariant across a wide range of Eastern and Western populations [10], suggesting their biological rather than cultural or learning-dependent basis. Already young children are able to indicate the bodily sensations associated with different emotions, and the sensations maps are tuned towards their adult-like representation during the development [11]. Finally, clinical studies also suggest that this tool might have diagnostic potential, as specific perturbation of the bodily experience of emotions is observed, for example, in schizophrenia [12]. All in all, the self-report data strongly points towards categorical organization of different emotions in the body.

## Towards total-body imaging of the emotion circuits

How can we resolve the seemingly discrepant results between the neuroimaging and self-report studies pointing towards discrete nature of emotions and the psychophysiological studies indicating lack of specificity? One opportunity would be simultaneous measurement of the central and peripheral axis of the emotional response. Although modern neuroimaging (fMRI and MEG) techniques allow quantifying brain basis of emotion simultaneously with autonomic activity, the peripheral physiological signals are rarely measured and when they are, the measurements are low-dimensional and biologically independent (i.e., acquired with different sensors/imaging methods) from the brain signals. To understand the systems-level biology of emotions, we need to go beyond such dualistic studies and measure the central-peripheral axis of the emotion circuit with high spatiotemporal resolution. Recent developments in total-body positron emission tomography (PET) [13] provides a novel means for simultaneous measurement of the central and peripheral activation of the emotion circuits using a unified approach (Figure 1B-C).

PET is the most sensitive technique for non-invasive imaging of human physiology and molecular pathways in living humans *in vivo*. The major advantage of PET is that the acquisition of the projection data is not limited by physical (e.g., gantry rotation in CT) or electronic (e.g., pulse sequence in MRI) scanning. Instead, the limits arise from the counting statistics of coincident photon detection. Conventional PET scanners have poor sensitivity for whole-body PET because a large proportion of the body is always outside the field of view of the scanner, and because majority isotopically emitted radiation does not intercept the detector rings. Total-body PET resolves both these problems by extending the detector rings allowing imaging of the whole human body with single positioning. This shifts the focus from dualistic studies on brain and periphery to simultaneous high-resolution imaging across brain and peripheral organs and creates an innovative new "multisystem" biology approach for studying systemic inter-organ interactions in emotion circuits, providing exciting opportunities for understanding the human emotion systems.

First, simultaneous imaging of the perfusion and glucose uptake of brain and peripheral tissues (myocardium, spleen, liver, skeletal muscle…) during different emotional states induced with pharmacological and behavioural protocols allows, for the first time, true biological quantification of the brain-body loops in human

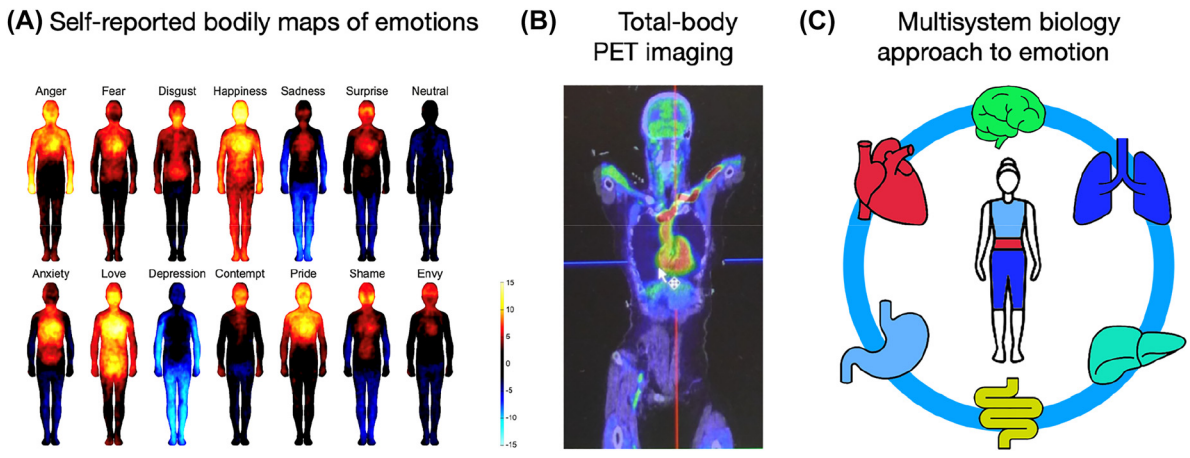


**Figure 1:** Mapping emotions on the body.
(A) Bodily maps of the self-reported sensations across 14 different emotions. (B–C) total. (A) reprinted with permission from [9] (B) courtesy of Juhani Knuuti from Turku PET Centre.

emotion circuits. This also allows detailed analysis of the central-peripheral interactions at the level of specific brain regions. Second, adoption of the whole-body approach to emotions and their disorders will be transformative for psychiatric research. For example, anxiety is symptomatic in numerous psychiatric disorders, and studies indicate that there is a bidirectional link between the anxious phenotype and cardiovascular disease (CVD). A large bulk of studies have established that limbic and paralimbic circuits focused on the amygdala are central to the development and maintenance of the anxiety state [14]. Long-term exposure to threats also imposes significant cardiorespiratory load, and anxiety is common in patients CVD [15]; conversely, anxiety disorders are a risk factor for coronary artery disease [16]. This link is corroborated by the fact that resting-state amygdala activity and concomitant anxiety is associated increased risk for cardiovascular disease events and arterial inflammation [17]. Total-body imaging would provide novel insight into the biological mechanisms behind the anxiety-driven CVDs as well as more generally the role of the peripheral physiology and interoceptive pathways in.

## Conclusions

The central-peripheral axis is tightly intertwined in emotions, but our understanding of the organization of the peripheral emotion circuits is still modest. The advent of high-resolution total-body imaging allows mapping the inter-organ interactions in the human emotion circuits and building a comprehensive picture of the discrete bodily basis of emotions in health and disease.

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