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The brain creates action-based maps of the world near the body

Certain neurons have visual and auditory receptive fields anchored to body parts. We show that these neurons reflect the value of interacting with objects near the body, not just their spatial locations. A collection of these neurons furnishes animals with an egocentric map: a predictive model of the near-body environment.

This is a summary of:
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The mission

Neurons that respond to objects near the body — peripersonal neurons — were discovered decades ago and initially viewed as simple proximity detectors[1,2]. Although this interpretation had substantial influence across neuroscience and related fields, proximity-based explanations have failed to explain more nuanced properties of these neurons, such as their modulation by stimulus valence, speed, and motor repertoire.

Research on peripersonal neurons has diversified considerably and includes behavioral and neuroimaging data from humans and animals. To avoid getting lost in ever-increasing amounts of disjointed data, we critically need a unified theoretical framework.

We aimed to address these issues by developing and testing a quantitative framework. Our theory explains the complex characteristics of peripersonal neurons, clarifies why they exist and how they function, and integrates them into broader theories of systems neuroscience.

The solution

We tackled the issue along three main lines involving reinforcement learning and computational modelling. First, our key insight was that peripersonal responses might simply reflect action values: the action-induced expected rewards or punishments from objects contacting our body[3] (Fig. 1). We tested this hypothesis by creating artificial neural networks (ANNs) trained to intercept or avoid objects (Fig. 1a) and observed whether similar body-part-centered responses would emerge naturally without being explicitly programmed. Second, we proposed a theoretical construct, an 'egocentric value map', which incorporates notions of network modularity, hierarchical decision-making, and compositionality[4]. This map is constructed from groups of peripersonal neurons, forming a more abstract, predictive model of the world near the body that allows rapid adaptation to novel situations. Third, we systematically tested our egocentric value map against extensive empirical data from multiple labs, including macaque neuronal recordings and human functional MRI, EEG, and behavioral data.

The neurons in our artificial agents naturally developed body-part-centred receptive fields that matched empirical findings from biological peripersonal neurons: they expanded with faster-moving stimuli, tool use, and higher-value objects (Fig. 1b). These ANNs also separate into sub-networks specialized for avoidance and interception, mirroring the modularity of both the macaque brain and the egocentric value map that we propose. We also demonstrated that a collection of peripersonal neurons can indeed create an egocentric map. Finally, the concept of egocentric value maps was the only theory to successfully fit extensive experimental data, outperforming alternative explanations and providing a generalizable framework for understanding peripersonal responses.

Future directions

This theory, besides providing multiple testable predictions, suggests that egocentric maps form a short-term, close-range counterpart to the long-term, long-range allocentric maps in the hippocampus. We propose a reciprocal relationship between these spatial maps, suggesting that egocentric maps serve as one-among-many building blocks for more complex allocentric maps[5], while allocentric maps provide contextual and task-specific information to egocentric maps. Beyond these conceptual implications, our work also has applications in fields such as neuroprosthetics and human–robot interactions. For example, robots could simulate egocentric value maps to develop adaptive, context-specific representations of appropriate human interaction distances, making human–robot collaboration more natural and effective.

Our theory still faces issues. For example, as it is framed in reinforcement learning, it lacks explicit parameters for sensory uncertainty. Also, while the theory we put forward excels at modelling aggregate measures such as EEG and reaction times, it remains difficult to disentangle the roles of individual biological neurons, because they might make differential and complicated contributions to action value. Finally, while body-part-centred fields are likely to reflect action value, not all representations of action value are body-part-centred. An egocentric value map is hence only one of many possible value maps that are likely to exist in the brain, with context determining which system guides behavior in different situations.

Next, we plan to test specific predictions generated by our model and to explicitly integrate uncertainty measures, potentially through different frameworks such as active inference. We also plan to collaborate across labs to model richer, more fine-grained and contemporary neuronal data.

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EXPERT OPINION

"This is an elegant, well-designed study showing how computational simulation of agent behavior-modulating action–reward relationships can result in the emergence of body-centered or proximity-dependent receptive fields, constituting peripersonal space (PPS). The computational work extends the theoretical contribution by the authors about conceptualization of PPS as value or action fields. It will be interesting to see how future work enables us to understand how this mechanism is implemented into a biological neural system." **Andrea Serino, University Hospital of Lausanne, Lausanne, Switzerland.**

FIGURE

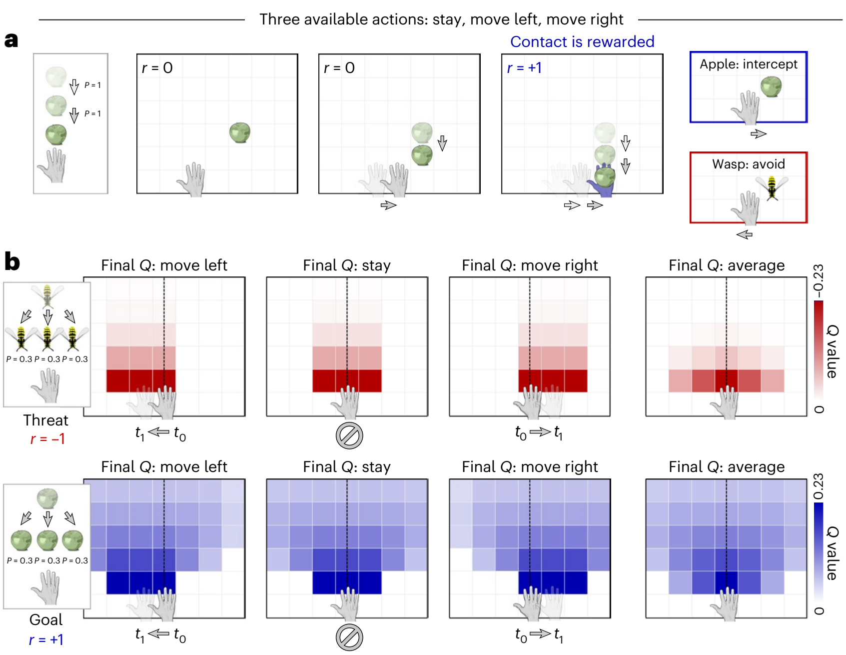

Fig. 1 | Action value creates body-part-centered fields shaped by motor repertoire. **a**, When objects offer rewards upon contact, agents maximize value by moving toward positive-reward objects (apple) and away from negative-reward objects (wasp). **b**, Motor repertoire shapes body-part-centered fields. Columns show *Q* values for different actions. For negative-reward stimuli, more available actions result in smaller fields, as agents can avoid threats more effectively. For positive-reward stimuli, more available actions expand fields, as agents can reach rewards more easily. This explains why biological peripersonal fields adapt according to action possibilities. © 2025, Bufacchi, R. J. et al.

BEHIND THE PAPER

Our journey into this field began serendipitously when we discovered proximity-dependent modulation of the hand-blink reflex during unfunded experiments done purely out of curiosity[3]. This 'blue skies' research ultimately led to our comprehensive theory, a reminder of the potential benefits of exploratory science. One initial struggle we faced was how the label 'peripersonal neurons' overemphasized spatial factors while missing their functional relevance. Another big surprise was that peripersonal neurons had been relegated to a niche compared to place cells, despite clear analogies between them. This drove our motivation to reintegrate this fascinating topic into mainstream neuroscience. After our 2018 paper[3] we thought our theory was complete, but implementing it mathematically revealed crucial shortcomings! This refinement process ultimately led to the more comprehensive framework presented here. It also strengthened our conviction that to determine which experimental questions are truly interesting, a robust theoretical framework helps guide your intuition. **R.J.B. & G.I.**

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   This paper shows how allocentric and cognitive maps can be constructed from cortical building blocks.

FROM THE EDITOR

"This work is intriguing as it provides a framework to understand the considerations our bodies make when interacting with the external environment, with relevance for the design of neurotechnology." **Henrietta Howells, Senior Editor, *Nature Neuroscience*.**