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Neuronal codes for predictive processing in cortical layers

Comment on Michael Gilead, Yaacov Trope, and Nira Liberman: “Above and Beyond the Concrete: The Diverse Representational Substrates of the Predictive Brain".

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Abstract: Predictive processing as a computational motif of the neocortex needs to be elaborated into theories of higher cognitive functions that include simulating future behavioural outcomes. We contribute to the neuroscientific perspective of predictive processing as a foundation for the proposed representational architectures of the mind.

Main text: By endeavouring to integrate predictive processing theories of brain function with human capacity for prospective thought, Gilead, Trope and Liberman have identified a subject matter that invites rigorous empirical focus. The current evidence for predictive processing is biased towards the field of perception. Such data is essential, but this bias leaves open questions about how neuronal prediction contributes to ‘offline’ brain processing in which we can flexibly traverse space and time in our mental activity. As cognition is predictive, we should now pursue a framework for predictive neuronal processing that is ‘abstracted away’ from proximal sensory inputs and used instead for prospective deduction or future simulation. The authors have initiated a thought-provoking account of how abstract representational elements supporting predictive cognition could be structured, and their structure bridges from perception science to cognitive psychology. We highlight the neurobiology of predictive processing as a subdivision for developing this framework.

Predictive brain frameworks prescribe specific neuronal processes. These processes can be summarized such that the hierarchical brain compares sensory inputs with internally generated models of the world, aiming to minimize error signals that indicate a mismatch and result in internal model revision (Friston, 2005). There are various mechanistic implementations of this computation (George & Hawkins, 2009; Spratling 2017), but broadly speaking, neuronal markers of prediction should reveal (aspects of) these coding principles. The authors have examined how neuroscience data, specifically human functional neuroimaging, corroborates their proposed structure of abstract representations. Brain signatures have been observed that support the distinct abstracta they describe, especially so for modality-specific and multimodal abstracta. The element of the model where “abstractness” is greatest, that is categorical abstracta and predicator representation, warrants to be investigated more sufficiently in brain imaging experiments testing predictive processing, but the authors provide a plausible hypothesis for how this could be realised in specific hubs of the default mode network (DMN). Under the assumption that identical computations (i.e. prediction) support all functions throughout the brain's hierarchy, the distinction between perceptual and cognitive processing is eliminated. As such, future data should confirm the hierarchy of inference differs in the content of mental representation at each layer (not the computation), and areas processing abstract representations for predictive cognition should reveal neuronal indicators of prediction. In line with this, the putative involvement of the default mode network in 'offline' processing to probabilistically simulate future outcomes can be described in the context of Markov Decision Processes (Dohmatob et al., 2018). This mathematical framework is in line with predictive neuronal processing in the default mode network, which is supported by experiments showing that the DMN overlaps with areas involved in forming associations (from which predictions are derived, Bar, 2007).

How close are we to testing a model of the predictive neural bases of conceptual cognition? Taking the perspective that the brain performs predictive cognition for mental time travel, one approach is to test the brain's generation of sensory inputs that are decoupled from perception. Mental imagery can be used to test internally-driven events, and such data have been interpreted within predictive processing frameworks. For example, analysis of functional magnetic resonance imaging data data reveals that vividness of visual imagery increases the top-down coupling of signals from frontal areas to early visual areas (Dijkstra et al., 2017). This finding fits with the role of cortical feedback carrying descending predictions from high to low areas, even in the absence of sensory input. Further, in primary sensory areas, brain imaging studies of illusions and mental imagery reveal that processing during perception is generative, for example, as observed visual counterstreams. In primary visual cortex it is possible to partition feedforward and feedback signals, this is crucial because these pathways transmit sensory versus internal processes respectively (or ascending prediction errors and descending predictions). We propose studying cortical layers in humans as a neuronal substrate allowing for mental time travel alongside perceptual processing. We motivate this hypothesis using high-resolution brain imaging showing that neuronal codes exist for abstract mental representations transferred by cortical feedback to sensory areas (Bergmann et al., 2019), and that sensory cortex allows for predictive processing mechanisms to be precisely spatiotemporally mapped (e.g. Edwards et al., 2017). Taking visual imagery as an example of counterfactual processing, deep cortical layers of visual cortex are involved in maintaining visual information specific to mental imagery (Bergmann et al., 2019). A dual stream of factual and counterfactual information processing might provide insight to higher cognitive functions in which potential future outcomes need to be simulated before informed decisions can be executed. The inherent challenge however in investigating prediction machinery in higher, abstract, psychological function is that we have diminished control over the content of internal representations and we have to probe brain areas that do not easily allow for the separation of sensory from internally-generated processes.

Developing the authors' account will now require, in part, overcoming the challenge of understanding if and how neuronal substrates of abstract mental representation, even those that confer predictive mental abilities such as projecting oneself forward in time, are one and the same as neuronal prediction. Towards the aim of a testable model of the neural bases of conceptual cognition, it will be essential to develop the description of higher cognitive functions within the parsimonious framework of predictive processing. This framework should span disciplines by defining common concepts and terminology. In doing so, it is imperative to avoid a language surplus as seen previously with terminology that was justified either on behavioural data alone, or in connection with specific paradigms, without providing a reduction into descriptions of neuronal processes. For example, attention has often been defined based on behavioural advantages without direct neuronal explanations, but might be more thoroughly and accurately explained as optimizing the precision of prediction error by increasing the synaptic gain of these neurons (Feldman and Friston, 2010; Gordon et al., 2019). The target article provides a descriptive framework of abstract representations for predictive cognition onto which we can map neuronal data, which should comprise neuronal recordings, simulated data and models, and behavioural measures in order to advance a parsimonious conceptual framework.

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