Interoceptive inference: from decision-making to organism integrity

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I enjoyed reading the interesting commentary by Gu and Fitzgerald [1] (henceforth G&F), which expands on aspects of the recently presented ‘interoceptive inference’ framework [2]. To recap, the basic idea of interoceptive inference is to apply the influential framework of predictive processing [3] to interoception, the sense of the internal physiological condition of the body. On this view, subjective feeling states – emotions – are generated by active ‘top-down’ inference on the (internal and external) causes of interoceptive signals, computed according to Bayesian principles. This idea generalises previous ‘cognitive appraisal’ theories of emotion [4] and points to common model-based predictive mechanisms underlying emotion and (exteroceptive) perception that come together in the experience of embodied selfhood [2].

G&F shift the spotlight from emotion and embodiment to physiological homeostasis and decision-making. This highlights active inference, whereby interoceptive predictions are fulfilled by action rather than by perception (i.e., changing the world/body, rather than changing the model; see [2]). Active interoceptive inference ensures homeostasis both directly via autonomic regulation and indirectly by shaping actions through influences on decision-making, so maintaining the organism in physiologically congenial environments. As they note, this directly inherits from Damasio’s influential somatic marker hypothesis [5], which postulates that emotional biasing signals arising from the body influence intuitive decision-making. They also rightly trace the relationship between homeostasis and interoceptive inference to the ‘free energy principle’ [6]. This is a generalisation of predictive processing which mandates that organisms – in virtue of their survival – must avoid ‘surprising’ states, where surprise is meant in an information theoretic sense as the negative log probability of the occurrence of an event. In the setting of interoception, this corresponds to maintenance of essential biological variables (e.g., blood pressure, heart rate) within specific viability bounds. G&F’s main point is that interoceptive inference contributes to physiological homeostasis in part by influencing value-based decision-making, neatly placing the somatic marker hypothesis in an embodied predictive coding context.

This brings to mind an interesting precursor to predictive processing in a seminal 1970 paper by W. Ross Ashby and Roger Conant entitled ‘Every good regulator of a system must be a model of that system’ (the body of the paper attempts a formal proof) [7]. This idea anticipates the free energy principle in saying that avoidance of atypical events (i.e., homeostatic regulation) necessitates a generative/predictive model of the causes of sensory inputs. Although it is left open whether such models need be explicitly encoded in control structures or can remain implicit in an agent’s phenotype, this correspondence between regulation/homeostasis and model-based inference nonetheless provides a formal motivation for predictive perception. Interestingly, the ‘avoidance of atypical events’ seems more intuitive for physiological states (as reflected in interoception) than for environmental states (as signalled by exteroception), where exploration of novel, atypical situations is sometimes necessary and often useful. From this perspective, it follows that interoceptive inference may be a more fundamental expression of the Bayesian brain than its original formulations in exteroceptive contexts like vision [3].

Returning to decision-making, it is well known that emotional dysregulation can disrupt choice behaviour [5]. However the precise mechanisms underlying somatic and interoceptive influences on decision-making remain unclear. Functionally, a role for interoceptive inference in decision-making suggests that intuitive decisions will be affected by the degree to which an individual maintains accurate predictive models of his/her own interoceptive states. In line with this idea and capitalising on individual variation in interoceptive sensitivity, Dunn and colleagues found that enhanced interoceptive sensitivity (measured by heartbeat counting) either helped or hindered intuitive decision-making, depending on whether anticipatory bodily signals favoured advantageous or disadvantageous choices [8].

Interoceptive inference goes further in emphasising the importance of precise timing of interoceptive signalling, an effect already demonstrated in the context of embodied selfhood [9]. Here, Garfinkel, Critchley, and colleagues have begun to detail how emotional and cognitive responses to stimuli that are affectively laden, and even conscious visual detection of these stimuli, is modulated by stimulus timing with respect to cardiac phase [10]. Examination of how these effects themselves modulate decision-making will shed important light on the role of interoceptive inference in this context.

Finally, the points raised by G&F could potentially apply to distinct affective disorders related to decision-making. For example, addiction could be re-construed as inappropriate active inference whereby strong interoceptive priors are
confirmed through action, overriding higher-order or hyperpriors relating to homeostasis and organismic integrity. Overall, I look forward to seeing how the framework of interoceptive inference will continue to integrate and illuminate interactions between cognition, perception, emotion, and, most interestingly, consciousness and self.

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