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Cognitive Science Below the Neck: Toward an Integrative Account of Consciousness in the Body

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Abstract

Our culture and its scientific endeavor direly need a holistic characterization of mind and body. Many phenomena attest to the profound effects of beliefs on bodily function (e.g., open-label placebo's effects on chronic pain) and interoceptive systems' role in mental processes (e.g., the emerging role of gut microbiomes in the mood). We need a mechanistic, integrative framework to account for these phenomena and generate novel predictions. Major advances have been made in understanding how the nervous system senses and regulates the body and in modeling how the brain implements the computations that subserve such activities. However, the vestiges of Cartesianism have entrained a style of thinking in which systems from the brainstem downward exist as the implementation layer of computational processes supporting sensation and behavior, rather than a complementary locus of information processing. As speakers and microphones, rather than other members of the chorus. We are thus forced to perceive well-documented, belief-driven phenomena like placebo, ritual,

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and psychosomatic disorders as mysterious obstacles or dubious allies rather than as a wellspring of potential.

Keywords: Belief; Interoceptive nervous system; Homeostasis; Allostasis; Bayesian modeling

1. Our proposal

To mechanistically understand how beliefs can manifest in bodily processes, cognitive science should begin by expanding its field of view below the neck and employing a formal language that accommodates translation between cognitive and bodily systems. We propose to use (I) Bayesian accounts of affective valence (parametrically deep allostasis, PDA; Hesp et al., 2021) to bridge (II) systems-neuroscience cortex-centric frameworks for integrating experience and belief with sensory information to optimally maintain life (i.e., embodied predictive interoception coding, EPIC; Barrett & Simmons, 2015), and (III) the crucial, holistic field of view afforded by Carvalho and Damasio's functional/anatomical account of the interoceptive nervous system (INS, 2021). This can help elucidate phenomena centered around structured belief—body interactions (e.g., ritual/clinical context, psychosomatic disorders) and embodied belief transmission (e.g., placebo, hypnosis) and frame them as emerging from properties of central nervous system (CNS)/INS dynamics.

2. The INS: Neurobiologically grounded/multiscale/below the neck

Carvalho and Damasio (2021) frame the spatiotemporally diffuse properties of interoception and affect as products of INS physiology. Light or absent myelination characterizes multiple areas and relays in the INS, such as C- and Aδ-fibers of the lamina I thalamocortical pathway, the trunk of the vagus nerve, the tractus solitarius, and periaqueductal gray. This lack of compartmentalization results in passive neurotransmitter diffusion outside of synaptic clefts and slower, more diffuse signaling. Additionally, it creates porous interfaces between the nervous system and blood at several points in the INS, by which the nervous system is brought into direct contact with the chemical makeup of the blood, thus acting as a chemoreceptor for the state of the organism (via concentrations of endogenous internal hormones and metabolites, etc.) as well as its interaction with the outside (via concentrations of exogenous chemicals). This is contrasted with the high-speed, spatiotemporally discrete computations of the exteroceptive/cognitive/proprioceptive systems (Allen & Tsakiris, 2018), based in neurotransmitter diffusion confined to synaptic clefts by myelination, fast, discrete signaling via largely myelinated axonal fibers, within a system enclosed by the blood-brain barrier (BBB). The INS's unique features relative to the CNS allow for distinct computational properties, permitting valenced, integrative, and continuous system regulation through continuous integration of peripheral interoceptive sensing with central processing, and construction of feelings as mental representations of bodily states whose valence tracks the fitness of life-maintenance.

3. PDA: Formal/multiscale

This continuous, integrative affective process in the service of predictive homeostasis (minimizing energy expenditure by anticipating future states) is formally reflected in Hesp et al. (2020, 2021) computational account of parametrically deep allostasis (PDA).They describe affect as a two-level Bayesian inference model in which a surface level uses afferent interoceptive and exteroceptive signals to anticipate homeostatic needs, while a deep-level inference continuously tracks the fitness of surface-level models, indexing fitness as affective valence. The valenced representations that result from the deep level are continuous, slow, and integrative—plausibly corresponding to the informational properties of the unmyelinated, nonsynaptic, porous INS. Importantly, these models allow for interpreting biological circuits *as if* they are implementing Bayesian logic, making them compatible with many possible biological instantiations (Andrews, 2021).

4. EPIC: Formal language/neurobiologically grounded

A biologically plausible implementation of such a model exists in the embodied predictive interoception coding (EPIC) model (Barrett & Simmons, 2015). EPIC posits a cortically distributive predictive system that (i) takes afferent information from the vagus nerve, CT-fibers, and spinothalamic tract, (ii) senses precision-weighted ascending homeostatic/metabolic and exteroceptive signals in highly laminated sensory "rich club" hubs (via the salience network), and (iii) issues allostatic predictions (via the default mode network) that drive descending allostatic control signals via projections to brainstem nuclei and compute prediction errors for feedback via efferent copies to L5 pyramidal neurons.

5. These accounts are compatible and complementary

These three accounts are compatible: All involve simultaneous fast and slow processes nested representationally within each other: (i) endocrine/paracrine, nonsynaptic-based signaling, and information processing in peripheral INS versus fast and directed synaptic processing in central INS; (ii) fast and distributed surface-level allostatic inference layer versus deep layer's slow tracking of the first layer's model fitness; and (iii) mirroring gradients of cortical laminarity and dimensionality compression (e.g., posterior vs. anterior insular cortex). This nesting aids in regulating causal relations in the body—world dyad to facilitate optimal homeostatic trajectories, guiding both internal and external action.

These accounts' scopes are complementary. Coarse grain or sparsity in one is met by fine grain and richness in the other(s). For example, while EPIC and PDA are more formally explicit, they lack the necessary field of view and functional considerations provided by the INS account. For the integrated view we propose, all three accounts (PDA, EPIC, and INS) are necessary, and none is sufficient on its own.

6. Returning to our thesis in light of these accounts

While the CNS/INS framework *crucially* expands our field of view beyond the cortex, Bayesian models frame belief such that it can work comfortably in the realm of mind—body interaction. Beliefs as "priors," that is, anticipatory framings ("taken once a day, this red pill should reduce your pain") can function as a "submerged" belief enacted in bodily function, reflecting the dynamic flow of consciously held priors into the INS over multiple nested time scales. The opposite can also occur—bodily signaling priors may conversely "emerge" to influence declarative awareness (e.g., analgesic medication can reduce the painful impact of social rejection). This submergence and emergence are likely an ongoing, dynamical process in the flow of consciousness that can be mapped onto the interplay of predictive and homeostatic signaling occurring constantly between the central and interoceptive nervous systems. Framed in this fashion, belief/priors are simply an assessment of the likelihood that shapes the interpretation of data, guided by embodied experience and evolution, whether originating or enacted in the body ormind.

7. Implications and applications

Our proposed approach can expand and deepen our understanding of the role of belief, ritual, and set/setting in research and clinical outcomes in a mechanistic yet intuitive manner. Three interrelated hypotheses follow from this that are amenable to experiment:

I. (i)The structure of belief is enacted in embodied processes. Consciously reconceptualizing pain as due to brain plasticity rather than physical injury nearly eliminated chronic back pain in 66% of sufferers, versus 20% (open-label placebo) and 10% (usual care) (Ashar et al., 2022), demonstrating that approaches targeting belief structures themselves may be more effective than open-label placebo (von Wernsdorff, Loef, Tuschen-Caffier, & Schmidt, 2021).
II. (ii)Beliefs transmitted between individuals can be subsequently enacted in bodily function, an effect that should be observable at related cognitive, affective, and interoceptive levels, and modulated by factors like suggestibility, trust, and beliefs about the intervention at hand (Christov-Moore et al., 2022; Jinich-Diamant et al., in preparation).
III. Interventions focused upon the body may prove effective in altering affect/belief structures, supporting novel avenues for diagnosing and treating psychopathology and effecting therapeutic change, for example, somatic therapy in the treatment of trauma (Brom et al., 2017; Kuhfuß, Maldei, Hetmanek, & Baumann, 2021).

Treating ritual context, belief, and mind—body interactions seriously in the context of modern medicine may provide a powerful, effective, and cost-saving ally for improved therapeutic outcomes. Pursuing these avenues additionally suggests the intriguing methodological necessity of spatially and temporally tracing signaling in the transition from CNS to INS as

a belief translates into bodily change, and vice versa. This will require novel methodological developments to enablefull-body dynamic imaging.

8. Conclusion

A field of view that encompasses cortical and interoceptive anatomy and computational processes, along with a formal language that allows us to speak of belief transmission and enactment between brain and body, will allow us to make testable predictions that can eventually transform mind—body mysteries into novel science and therapy. Much will be gained if cognitive science can rigorously venture below the neck, more fully keeping the body in mind.

References

Allen, M., & Tsakiris, M. (2018). The body as first prior: Interoceptive predictive processing and the primacy of self-models. In M. Tsakiris & H. De Preester (Eds.), *The interoceptive mind: From homeostasis to awareness*. Oxford University Press.

Andrews, M. (2021). The math is not the territory: Navigating the free energy principle. *Biology & Philosophy*, *36*, 30.

Ashar, Y. K., Gordon, A., Schubiner, H., Uipi, C., Knight, K., Anderson, Z., Carlisle, L., Geuter, S., Flood, T. F., Kragel, P .A., Dimidjian, S., Lumley, M. A., & Wager, T. D. (2022). Effect of Pain Reprocessing Therapy vs Placebo and Usual Care for Patients With Chronic Back Pain: A Randomized Clinical Trial. *JAMA psychiatry*, *79*(1), 13–23. https://doi.org/10.1001/jamapsychiatry.2021.2669

Barrett, L. F., & Simmons, W. K. (2015). Interoceptive predictions in the brain. *Nature Reviews Neuroscience*, *16*, 419–429.

Brom, D., Stokar, Y., Lawi, C., Nuriel-Porat, V., Ziv, Y., Lerner, K., & Ross, G. (2017). Somatic experiencing for posttraumatic stress disorder: A randomized controlled outcome study. *Journal of Traumatic Stress*, *30*(3), 304–312.

Carvalho, G. B., & Damasio, A. (2021). Interoception and the origin of feelings: A new synthesis. *Bioessays*, *43*, e2000261.

Hesp, C., Smith, R., Parr, T., Allen, M., Friston, K. J., & Ramstead, M. J. D. (2021). Deeply felt affect: The emergence of valence in deep active inference. *Neural Computation*, *33*, 398–446.

Hesp, C., Tschantz, A., Millidge, B., Ramstead, M., Friston, K., & Smith, R. (2020). Sophisticated affective inference: Simulating anticipatory affective dynamics of imagining future events. In T. Verbelen, P. Lanillos, C. L. Buckley, & C. De Boom (Eds.), Active inference. *Communications in Computer and Information Science* (pp. 179–186). Cham: Springer International Publishing.

Kuhfuß, M., Maldei, T., Hetmanek, A., & Baumann, N. (2021). Somatic experiencing — Effectiveness and key factors of a body-oriented trauma therapy: A scoping literature review. *European Journal of Psychotraumatology*, *12*(1), 1929023.

von Wernsdorff, M., Loef, M., Tuschen-Caffier, B., & Schmidt, S. (2021). Effects of open-label placebos in clinical trials: A systematic review and meta-analysis. *Scientific Reports*, *11*, 3855.