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A call for comparing theories of consciousness and data sharing

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Abstract

Merker, Williford, and Rudrauf make several arguments against the integrated information theory of consciousness; whereas some have merit, their conclusion that the theory should be discarded is premature. Coming years promise advances in the empirical study of consciousness, and only after theories are independently tested with shared data can they be ruled in or out. We propose future research directions.

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Merker, Williford, and Rudrauf argue that the many unanswered aspects of integrated information theory (IIT) condemn it as a failed theory of consciousness. They make several important points about the ways in which IIT is underspecified – for example, how first-person phenomenology is missing in the IIT formalism, or more generally how integrated information alone could be *synonymous* with consciousness. These are important concerns.

However, at this young stage of understanding the neuroscience of consciousness, under-specification does not equal incorrectness. For example, the authors argue that IIT is computationally challenging, preventing it from being currently tested on brain data. But computational difficulty does not by itself reflect on the legitimacy of a hypothesis. Another criticism asserts that if IIT were correct, that could imply consciousness in other complex systems. But the authors leverage no data to establish why consciousness in other biological systems is impossible. In sum, their criticisms can only be taken as suggestions for digging in, rather than a definitive ruling out.

As the authors correctly highlight, the field needs more experimentation to directly test theories against one another. We argue that synthesis and open sharing of data, along with multiple comparative studies, are needed to facilitate this. We make a plea for sharing relevant neurophysiological and neuroimaging data to propel the field forward and resolve the kind of issues raised by the authors.

Such a community effort will allow many theories to be more easily pitted against one another. For example, in addition to IIT, prominent theories of consciousness include *global ignition* (sudden, widespread activation of neuronal processes), *global workspace* (incoming information becomes globally available across diverse integrated brain systems), and *re-entrant processing* (signaling along reentrant paths integrates activity from different brain regions). These theories can be tested by measuring neural activity associated with conscious perception, such as alterations in directional flows (causality), dynamic state, connectivity, or information integration (complexity) of brain processing (Cai, Ryali, Pasumarthy, Talasila, & Menon, 2021). Experiments involving the presentation of simple touch stimuli presented near perceptual thresholds, combined with haptic masks or sounds, can be used to identify alterations in network activity associated with conscious processing (Meador *et al*., 2017b). If a neural marker related to a theory is proposed to be uniquely associated with conscious processing, but is observed under non-conscious conditions, that theory is undermined.

Analyses of neural data from large-scale, multi-electrode electrophysiological recordings could offer even more insight. For example, the recent *detect*, *pulse*, *switch*, *and wave* model (Herman et al., 2019), which implies widespread integration and broadcasting across neural networks, is consistent with the global workspace theory (Dehaene & Naccache, 2001; Menon & Uddin, 2010; Sridharan, Levitin, & Menon, 2008). As another example, changes in directional processing flows would support theories of re-entrant processing. Changes in brain dynamics or connectivity would support theories of global ignition or global workspace. Changes in complexity would support the IIT. Surprisingly, direct comparison of these theories in the same dataset with sophisticated analyses of networks has never been performed.

Many experimental approaches can be leveraged. First, psychophysical manipulation of conscious perception can lead to measurable changes. For example, masking a touch will redirect changes to the hemisphere contralateral to the mask. A sound presented ipsilaterally to a target touch stimulus will increase detectability of the touch and produce a unique neural signature corresponding to conscious perception. In contrast, a sound opposite the touch will decrease detectability, exerting opposite effects on neural signatures of conscious perception. Extant published data from these studies could be readily shared via several platforms, such as OpenNeuro (Sherif et al., 2014; Vogelstein et al., 2018).

Second, pharmacological agents are a powerful tool for disrupting arousal and information processing networks. Such agents can be leveraged with specificity, as anesthesia is not simply an on/off switch for consciousness. Instead, certain anesthetic and adjuvant agents (e.g., ketamine, propofol, nitrous oxide, and barbiturates) selectively disrupt unique neurotransmitter systems, impacting different arousal and sensory processing networks (Bonhomme *et al*., 2019; Purdon, Sampson, Pavone, & Brown, 2015). Administration of different anesthetic agents results in unique electrophysiological signatures both at the single channel (Eagleman, Chander, Reynolds, Ouellette, & Maciver, 2019; Eagleman, Drover, Drover, Ouellette, & MacIver, 2018a; Eagleman et al., 2018b) and multi-channel network level (Eagleman & Drover, 2018; Lee & Mashour, 2018) when using electroencephalogram (EEG) in humans. A strong contender for a theory of consciousness would have to explain data resulting from different agents (Mashour, 2006). As one example, computational measures used in IIT can significantly discriminate between awake and anesthetized states even when patients are anesthetized with different agents (Casali et al., 2013; Sarasso et al., 2015).

Finally, patient populations with unique sensory abilities or cognitive challenges present opportunities to compare theories of consciousness; we discuss four examples. First, conditions such as synesthesia (in which a person's senses are blended) are increasingly being subjected to neuroimaging and genetic analysis to understand the subtle differences that lead to slightly different states of consciousness (Cytowic & Eagleman, 2011; Tomson, Narayan, Allen, & Eagleman, 2013). Second, people with neglect syndrome cannot consciously perceive real-time stimuli or even spatial memories from the hemispace contralateral to a brain lesion

(Meador, Loring, Bowers, & Heilman, 1987, 2000). Third, corpus callosotomies in people with epilepsy give an opportunity to witness information processed independently by each hemisphere. Perceptions requiring high-level, hemisphere-specific cortical functions (e.g., language) may not access conscious perception for stimuli ipsilateral to that hemisphere, but simple stimuli may access conscious perception irrespective of hemispace, suggesting that simple stimuli are integrated subcortically (Meador, Loring, & Sathian, 2017a). Fourth, psychiatric disorders including dissociation syndromes offer a way to probe altered consciousness states and evaluate whether changes in IIT or brain network integration, more broadly, predict clinical symptoms (Menon, 2021).

In summary, there are a growing number of approaches to refine, and possibly rule-out, different theories of consciousness. We are entering a golden age of measurement, analysis, and data sharing that make this endeavor possible in the coming years. However, progress will require independent testing of different theories and keeping an open mind until science can rule theories out.

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Conflict of interest

None.

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