From complexity to consciousness

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**Complexity as an explanatory correlate of consciousness:
Reply to ‘Islands of awareness or islands of cortical complexity?’**

Tim Bayne

School of Philosophical, Historical, and International Studies, Monash University, Melbourne, Australia

Canadian Institute for Advanced Research, Azrieli Program in Brain, Mind and Consciousness, Toronto, Canada

Anil Seth

School of Engineering and Informatics, University of Sussex, Brighton, UK

Sackler Centre for Consciousness Science, University of Sussex, Brighton, UK

Canadian Institute for Advanced Research, Azrieli Program in Brain, Mind and Consciousness, Toronto, Canada

Marcello Massimini

Department of Biomedical Clinical Sciences, University of Milan, Milan, Italy
5IRCCS, Fondazione Don Gnocchi, Milan, Italy

Canadian Institute for Advanced Research, Azrieli Program in Brain, Mind and Consciousness, Toronto, Canada

Canadian Institute for Advanced Research, Azrieli Program in Brain, Mind and Consciousness, Toronto, Canada

Correspondence: timothy.bayne@monash.edu (T.B.)

We thank Cecconi and colleagues for their probing questions about our Opinion paper “Are There Islands of Awareness?” [1], and we are grateful for the opportunity to return to these important issues.

Our primary aim in writing the forementioned paper was to give the notion of an island of awareness (IOA) some precision, and to argue that the possibility of IOAs should not be dismissed as a philosophical fantasy but should be taken seriously by the science of consciousness.

The fundamental challenge, of course, concerns the detection of IOAs. What would count as good evidence for the presence of an IOA? We suggest that the most promising approaches involve complexity measures, such as the Perturbational Complexity Index and other measures that are sensitive to coexistence of functional differentiation and functional integration in neural systems. We point to these particular metrics because they go beyond mere correlation to operationalize explanatory relationships between neural dynamics and phenomenological properties [2, 3] and because they have already been shown to perform well when assessing consciousness in patients in whom devastating injuries often result in disconnection from inputs and outputs [4, 5]. Thus, we propose to use a “radar” that we have learned to trust to explore the unknown landscape of completely disconnected brains.

Cecconi et al. [*insert here reference to the Letter by Cecconi et al., this issue of TINS*] raise two interesting issues in connection with this proposal. The first is that these measures treat consciousness as a one-dimensional phenomenon, which -- Cecconi and colleagues argue -- is mistaken. We agree that consciousness is multidimensional [6], but we don't agree that the use of complexity measures to detect consciousness presupposes that it is unidimensional. The key here is to realize that markers or indicators of consciousness need not be treated as definitions of consciousness. (Compare: crying is a marker of pain, but pain is not to be defined in terms of crying.) Consciousness could be multidimensional even if certain markers of it are unidimensional. (Cecconi and colleagues ask whether we mean to refer to subjective experience when speaking of consciousness. We do.)

The second issue that Cecconi et al. raise concerns the use of complexity measures to identify IOAs. There are two aspects to this challenge. The first is whether it is possible to directly compare values of complexity that have been derived from different types of systems. For example, one cannot directly compare the values of the slice-adapted version of PCI (sPCI) to those validated in humans, in part because they are currently obtained with different techniques at different scales [7]. Determining what counts as the ‘most appropriate’ scale for a given system is challenging, but recent advances in the mathematical

analysis of multiscale systems have made progress in addressing it [8, 9].

Accompanying these technical considerations is the more general question of whether it is ever legitimate to apply markers of consciousness that have been validated in one population (whole human beings) to the members of other populations, such as ex cranio brains, disconnected hemispheres, and cerebral organoids. Cecconi et al. appear to answer this question in the negative. We will confine our response to three points. First, anyone who is willing to ascribe consciousness to non-human animals faces a version of this challenge, for the behavioural and neurophysiological markers of consciousness that we employ to ascribe consciousness to non-human animals must themselves be validated with reference to human beings [10]. Second, the systems we are considering share many of our biological features; in particular, they have neurons and associated biological infrastructure. Concerns about the possible substrate dependency of consciousness can therefore be set aside (compare, for example, silicon-based AI systems). Third, as we note above and in [1], our validation strategy appeals to the capacity of the property in question to explain features that are associated with consciousness, starting from its unity and richness. This approach to validation—the ‘natural kind’ [11] or ‘explanatory correlate’ [12] approach—arguably supports greater confidence in the applicability of measures of consciousness to ‘novel populations’ than do correlational approaches to validation. For this reason, the analogy that Cecconi et al. draw with temperature and health fails.

There is always some risk in applying a marker of consciousness to ‘difficult cases’. The central issue is one of risk management: would the level of risk associated with ascribing consciousness to disconnected hemispheres, ex cranio brains, or cerebral organoids be unreasonable? We take a pragmatic view. The recent emergence of candidate IOAs in clinical settings and in neurotechnology laboratories raise questions about consciousness that cannot be ignored. Although current complexity measures are imperfect and must be interpreted in context, they remain our most promising guide to this uncharted terrain.

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