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Distinctions between brain structure, complexity, and function. Comment on "Does the brain behave like a (complex) network? I. Dynamics" by Papo and Buldú

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1. Summary

Papo and Buldú [1] provide an expansive review of results in complexity and network neuroscience. Their review broadly focuses on the question: *Is complex brain-network topology necessary for complex brain dynamics?* The authors summarize extensive evidence that links topology to dynamics but, despite this wealth of evidence, conclude that the question remains unsettled. Here, I discuss that we can reconcile this seeming disconnect by clarifying terms such as *structure, complexity*, and *function*. We can do so, specifically, by first defining complex dynamics as a type of structure—and thus clearly distinguishing and separating it from function—and then using this definition to meaningfully subdivide the original question into two: a question that is settled but unimportant, and a question that is important but unsettled.

2. Introduction

Thousands of studies over the last two decades have modeled data on neural anatomy and activity as networks of interacting elements. Such networks can take many forms: from neurons linked by synapses; to brain regions linked by common patterns of development, anatomy, or activity; to more abstract representations. The topology of these brain networks (in other words, the arrangement of network interactions) is often termed "complex" when it combines aspects of ordered clustering and disordered randomness. Many studies in network neuroscience have assumed that complex topology is fundamentally important. Papo and Buldú [1] question this assumption by asking if complex topology is necessary for complex dynamics. They suggest, specifically, that brain networks only "behave like complex networks" if they give rise to complex dynamics.

Papo and Buldú describe extensive links between topology and dynamics (see, especially, the section "Signs of brain networkness: dynamic relevance of network structure" and references therein). On the basis of this considerable existing evidence, one may conclude that complex brain-network topology is necessary for complex brain dynamics. Papo and Buldú, however, offer a more cautious conclusion: "Whether and how a network structure underlies the emergence of non-trivial brain activity fluctuations are important though to a large extent still open questions". This disconnect between the extensive evidence and the cautious conclusion thus presents an interpretational ambiguity.

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Table 1
Clarifications of relevant terms.

Term	Definition
Structure	Any anatomical or physiological organization. Structure encompasses all anatomical and physiological phenomena and therefore includes both network topology and dynamics.
Complexity	Structure that includes elements of order and disorder. Complexity encompasses all network topological complexity as well as all dynamical complexity.
Function	Physiological activity that helps animals to survive and reproduce.

3. Clarifications

Ambiguities in systems neuroscience often arise from usage of terms that have several distinct meanings. Clarifications of these terms can often help resolve the ambiguities. Indeed, the need for the cautiousness of Papo and Buldú becomes apparent once we clarify the terms *structure, complexity*, and *function* from their paper (Table 1, adapted from Reference [2]).

These definitions now allow us to subdivide the original general question—*Is complex brain-network topology necessary for complex brain dynamics?*—into two more specific questions:

Question 1: *Is one type of complex structure (brain-network topology) necessary for another type of complex structure (brain dynamics)?* The multitude of links between brain-network topology and dynamics—comprehensively described by Papo and Buldú—suggest that this question is generally resolved. At the same time, this question does not seem to be especially important, insofar as structure, whether simple or complex, is unimportant if it has no clear links to function. Complex emergent dynamics often mesmerize us [3] but they are also often non-functional. For example, in some cases, artificial dynamical systems without known function can produce complex dynamical phenomena [4] while in other cases, specific neural function (such as sensation or action) gives off intricate but epiphenomenal dynamics [5]. In this sense, studies of links between brain structure and dynamics—including structural and functional connectivity in network neuroscience [6]—are, in reality, studies of structure-structure relationships (rather than structure-function relationships), unless they additionally demonstrate strong links between dynamics and function.

Question 2: *Is one type of complex structure (brain-network topology) necessary for function?* This seems to be the important and unresolved question that forms the ultimate focus of Papo and Buldú. Indeed, the authors allude to this throughout the text—"-Throughout, the discussion focuses on bare dynamics, as opposed to genuine functional brain activity, which will instead be formally defined, differentiated from the former and examined in a companion paper (Papo and Buldú, in preparation)."—and I look forward to reading their forthcoming paper on this topic.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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