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Review

Topodynamics of metastable brains

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Abstract

The brain displays both the anatomical features of a vast amount of interconnected topological mappings as well as the functional features of a nonlinear, metastable system at the edge of chaos, equipped with a phase space where mental random walks tend towards lower energetic basins. Nevertheless, with the exception of some advanced neuro-anatomic descriptions and present-day connectomic research, very few studies have been addressing the topological path of a brain embedded or embodied in its external and internal environment. Herein, by using new formal tools derived from algebraic topology, we provide an account of the metastable brain, based on the neuro-scientific model of Operational Architectonics of brain–mind functioning. We introduce a "topodynamic" description that shows how the relationships among the countless intertwined spatio-temporal levels of brain functioning can be assessed in terms of projections and mappings that take place on abstract structures, equipped with different dimensions, curvatures and energetic constraints. Such a topodynamical approach, apart from providing a biologically plausible model of brain function that can be operationalized, is also able to tackle the issue of a long-standing dichotomy: it throws indeed a bridge between the subjective, immediate datum of the naïve complex of sensations and mentations and the objective, quantitative, data extracted from experimental neuro-scientific procedures. Importantly, it opens the door to a series of new predictions and future directions of advancement for neuroscientific research.

Keywords: Topology; Borsuk–Ulam theorem; Nonlinear dynamics; Central nervous system; Mind

Abbreviations: BUT, Borsuk–Ulam theorem; FPT, fixed point theorem; IPST, internal physical space–time; OA, operational Architectonics; OM, operational module; OST, operational space–time; PST, phenomenal space–time; RTP, rapid transitive period.

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0. Introduction

Over the last several decades, there has been an explosive development of new theories regarding brain and mind functioning as well as new powerful techniques that facilitate innovative experimental studies (see for example, [1–3]. However, none of these theories exploits in an *explicit* way the actual physical (brain) and subjective (mind) *operations* the human brain–mind performs in the course of behavior. The recently proposed Operational Architectonics (OA) framework of brain–mind functioning [4–10], by contrast to other theories, sets out with the explicit aim to describe, measure and model the brain and mind operations involved in the development of the most complex human behaviors, as governed by the brain. It is self-evident that both brain and mind functioning have intertwined temporal structure defined by their respective operations [11–13], where metastable changes of brain spatiotemporal patterns are isomorphic with cognitive and phenomenal levels [8,10].

This paper aims to throw a bridge between the above-mentioned OA model and the far-flung branch of algebraic topology. Indeed, topology, in assessing the properties that are preserved through deformation, stretching and twisting of objects, is an underrated methodological approach with countless possible applications [14–18]. In particular, the Borsuk–Ulam theorem (BUT), cast in a quantitative fashion which has the potential of being operationalized, stands for a universal principle underlying a number of natural phenomena [19]. BUT states that, if a single point on a circumference projects to a higher spatial dimension, it gives rise to two antipodal points with matching descriptions, and vice versa (Fig. 1A) [20–23]. Points on a sphere are *antipodal*, provided they are diametrically opposite [24], such as, for example, the poles of a sphere. This means, e.g., that there exist on the earth's surface at least two antipodal points with the same temperature and pressure. BUT looks like a translucent glass sphere between a light source and our eyes: we watch two lights on the sphere surface instead of one. But the two lights are not just imagined, they are also real with observable properties, such as intensity and diameter. This means that two antipodal points can be described at one level of observation, while relative to just a single point at a lower level [18,25]. Here we will show that BUT and its recently developed variants allow the assessment of brain functioning in terms of affinities and projections from real spaces to abstract ones.

This paper comprises four sections. The first section introduces the model of Operational Architectonics that considers the brain as a metastable system, thus placing the brain in the broader framework of dynamical systems theory. The second section illustrates, in plain terms accessible for a broader audience, the topological apparatus able to quantitatively describe the activity and function of the metastable brain. In particular, we will go through novel variants of the above mentioned BUT. The third, crucial, section throws a bridge between the two first parts, assessing the activities of the brain operational architectonics in terms of algebraic topology. We termed this novel approach "*brain topodynamics*". In the fourth section, we mention several predictions and new research directions that follow from the OA/topological framework. This section aims also to answer the most important question: in the context of OA, what does such topodynamical approach bring to the table, with respect to both conceptual and operational points of view? What new predictions can be established and what new research directions might be followed?

1. Brain metastability and brain–mind operational architectonics model

Recently a novel paradigm in relation to the brain–mind functioning is beginning to emerge—it stresses the dynamic balance between isolated functions of local neuronal assemblies and globally coordinated activity among them [8,12,13]. In this new view, the potential multivariability of the neuronal assemblies and their larger conglomerates (networks) appears to be far from continuous in time, but confined by the dynamics of short-term local and global *metastable* brain states [26]. As it has been proposed, metastability is an entirely new conception of brain functioning, where the individual parts of the brain exhibit tendencies to function autonomously at the same time as they exhibit tendencies for coordinated activity [11,26–28]. Specifically, *metastability* (when the system's degrees of freedom are restricted) is circumstantial for the interaction among the elementary neuronal systems (neuronal assemblies) in order to generate adaptive behavior within changing and not fully predictable environments: "By synchronizing the stable microstates of the 'microscopic variables' during certain periods, the neuronal systems (neuronal assemblies) have the possibility for interactive information exchange of the essential variables, which are important for the acceptance and