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Research

Multistability and metastability: understanding dynamic coordination in the brain

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Multistable coordination dynamics exists at many levels, from multifunctional neural circuits in vertebrates and invertebrates to large-scale neural circuitry in humans. Moreover, multistability spans (at least) the domains of action and perception, and has been found to place constraints upon, even dictating the nature of, intentional change and the skill-learning process. This paper reviews some of the key evidence for multistability in the aforementioned areas, and illustrates how it has been measured, modelled and theoretically understood. It then suggests how multistability—when combined with essential aspects of coordination dynamics such as instability, transitions and (especially) metastability—provides a platform for understanding coupling and the creative dynamics of complex goal-directed systems, including the brain and the brain–behaviour relation.

Keywords: coordination dynamics; metastability; multistability; instability; transitions; complementarity

1. INTRODUCTION

In addressing the subject of multistability, we are advised to follow Socrates: first ask what? Then ask why? So, what is multistability and how do we understand it? In previous work, my colleagues and I have considered multistability and its cognate aspects (fluctuations, instability, transitions, metastability, hysteresis, adaptation, etc.) in vision, speech, language, motor and neural dynamics ([1]; see also earlier studies [2–4] for related approaches). In the last 15 years, many empirical generalizations and modelling developments have taken place on the subject, at least in part owing to the advent of structural and functional neuroimaging and increasingly sophisticated analysis and computational modelling tools. Here, however, after a few general words on what multistability is, I wish to focus on the question of *why* multistability occurs in the first place. For that one has to go beyond traditional disciplinary boundaries and fully embrace the science of complex systems tailored to the goal-directed and functional aspects of living things—coordination dynamics—where multistability is not some freak phenomenon [5], but rather is close to the very core of the way things are. The hope is that asking the why question may reshape our perspective by providing not only a language for understanding multistability but also a rationale for its occurrence, indeed its ubiquity.

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One contribution of 10 to a Theme Issue 'Multistability in perception: binding sensory modalities'.

2. WHAT IS MULTISTABILITY?

Multistability is a universal, essentially nonlinear aspect of matter and its organization—from molecular arrangements and chemical reactions to multistability in the meaning of words and actions and beyond [6]. When we talk of multistability, we are usually talking about stable states or attractors; the stability of a state depends on how quickly the system returns to a state following a perturbation.[1] In the brain, attractors correspond to stable patterns of reverberating activity in neural populations that support and sustain themselves. The image is one of a changing dynamic landscape where population activity shifts from one attractive state to another. Fluctuations in the nervous system occur on many levels, from channel noise in synaptic transmission to neural populations and neural networks ([7] for review), destabilizing self-sustaining patterns and causing switching from one attractor state to another. A specific example comes from recent biophysical modelling [8] in which multistability and scale-invariant fluctuations arise in resting state cortical activity as a result of noisy input into thalamic neurons modulated by cortical feedback. In short, if a system has multiple coexisting attractors and noise is sufficiently strong to cause switching among stable states, it may be said to be multistable.

Understanding multistability may proceed in (at least) two ways. In the first, one may seek specific *mechanisms* for a given instance of multistable phenomena. The search for specific mechanism proceeds by identifying the physico-chemico-bio-psycho- basis of a chosen exemplar of interest. A second way is to seek dynamic *laws* and principles of multistability. In this