Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

Current Opinion in Neurobiology

The Kantian brain: brain dynamics from a neurophenomenological perspective

Sina Fazelpour and Evan Thompson

Current research on spontaneous, self-generated brain rhythms and dynamic neural network coordination cast new light on Immanuel Kant's idea of the 'spontaneity' of cognition, that is, the mind's capacity to organize and synthesize sensory stimuli in novel, unprecedented ways. Nevertheless, determining the precise nature of the brain-cognition mapping remains an outstanding challenge. Neurophenomenology, which uses phenomenological information about the variability of subjective experience in order to illuminate the variability of brain dynamics, offers a promising method for addressing this challenge.

Addresses
Department of Philosophy, University of British Columbia, 1866 Main Mall, Vancouver, BC V6T 1Z1, Canada

Corresponding author: Thompson, Evan (evan.thompson@ubc.ca)

Current Opinion in Neurobiology 2015, **31**:223–229

This review comes from a themed issue on **Brain rhythms and dynamic coordination**

Edited by **György Buzsáki** and **Walter Freeman**

http://dx.doi.org/10.1016/j.conb.2014.12.006

Introduction

What implications do contemporary views of the brain as a complex, self-organizing system with nonlinear dynamics [1] have for longstanding philosophical considerations about the relationship between the mind and the world? Here we highlight basic theoretical ideas and relevant empirical data regarding brain rhythms and dynamic coordination that indicate that mental phenomena arise from the brain's self-organized and spontaneous, pattern-generating activity, and not simply from stimulus-driven processing [2•,3]. We call this view 'the Kantian brain' [4] because it confirms Immanuel Kant's (1724–1804) idea of the 'spontaneity' of cognition, by which he meant the capacity to organize and automatically synthesize sensory stimuli in unprecedented ways relative to those stimuli, thereby yielding novel, structured cognitions [5,6]. As a number of theorists have emphasized, spontaneous and self-organized brain activity is a complex and large-scale expression of basic phenomena of biological self-organization [7–9]. Here, too, we find support for Kantian ideas, for Kant also argued that being self-producing — 'autopoietic,' in contemporary terms [7] — was the distinguishing property of living beings [10–12]. Nevertheless, despite these insights from philosophy and modern science, determining the precise nature of the mapping between the neural level of network activity and the psychological level of mental function — the brain and the mind — remains an outstanding challenge, especially given the increasing evidence that this mapping is likely to be many–many rather than one–one [13•,14••]. Furthermore, the challenges multiply if we aim to include consciousness — the subjective and experiential aspects of the mind — as part of the mapping [15]. We propose that, to make headway on these challenges, we need to add the theoretical perspective and methodological approach of 'neurophenomenology' [16] to that of the Kantian brain, thereby paralleling the philosophical evolution from Kant to phenomenological philosophy of mind [17], while enriching phenomenology with the tools of neuroscience and experimental psychology. Neurophenomenology stresses the usefulness of obtaining detailed, first-person reports of moment-to-moment subjective experience in order to uncover information about brain rhythms and dynamic coordination relevant to mental functions and consciousness [18,19,20••]. After briefly reviewing neurophenomenology in the second part of this paper, we conclude by highlighting its usefulness for relating spontaneous, self-organized brain activity to self-generated, spontaneous cognition [21].

The Kantian brain

Consider that, at each moment, our perceptual engagement with the environment is rich and complex: we are faced with a world filled with sights, sounds, and smells, among many other things, which we experience as objects and events located in space and time. Moreover, what we perceive shows up with varying degrees of significance and relevance, depending on our current states of expectation, attention, motivation, and emotion [22]. Despite this diversity, however, each perceptual moment is experienced as a unified whole [23]. Furthermore, as perception unfolds, the successive moments seem to constitute a coherent, integrated stream [24]. As Kant famously argued [5], such synchronic and diachronic unities characteristic of perception occur as a result of an organizing and synthesizing function belonging to the mind's self-activity. Kant called this function 'spontaneity' and distinguished it from 'receptivity', which is the capacity to receive sense impressions. Thus, according to Kant, to explain perception we cannot proceed just by considering stimulus-induced responses to sensory input; rather, we must take account of the ongoing, intrinsic, and spontaneous self-organizing activity of the mind, and the rules or laws governing it.

We can contrast this idea with the view that the overall function of the mind in perception is to represent the external world by discriminating various features of the sensory input, a function that can be decomposed into a set of more specific subfunctions, each devoted to detecting distinct features with differing degrees of complexity. At the level of neuronal implementation, this view takes each subfunction to map uniquely onto a distinct population of neurons [25] or anatomical region [26], with more complex features being processed further away from the sensory detectors. The functional organization of the brain, therefore, is seen as consisting in the serial, bottom-up processing of the sensory input along hierarchically organized pathways or cortical areas [27].

Neuroscientific studies of structural and functional brain connectivity in the past two decades, however, provide strong support for a view of the mind much closer to that which Kant envisioned. Neural structures sustaining perceptual functions are seen as involving parallel processing within networks of widely distributed regions whose functional connectivity is mediated by the coherent oscillatory activity across the affiliated regions of the networks themselves [1,2•,3,28]. The high degree of recurrent connections within these networks further indicates the constitutive role of the brain in dictating the significance of the incoming sensory input in light of the organism's current states of expectation, motivation, and attention [29,30]. According to longstanding ideas from neural network research [31,32•] and predictive coding theories [33–35], perception comprises competitive interactions between feedback and feedforward pathways at multiple hierarchical levels, with feedback pathways carrying generated expectations or predictions about incoming sensory signals, and feedforward pathways conveying the mismatch between the expectations or predictions and the sensory input. Furthermore, such feedforward and feedback interactions occur within the larger context of the ongoing, metastable activity of the entire brain network [3,8,36,37,38•], which also involves the homeostatic and affective states of the body mediated through the various structural connections between the cortex and subcortical structures, including the hypothalamus and amygdala [22,39]. Thus, far from viewing the brain as a stimulus-driven device, these theories and findings indicate that the brain is an active system engaged in modeling the world in and through its self-generated activity in close coupling with the rest of the body.

Bridging brain and mind

From the foregoing perspective on the Kantian brain, we should not expect there to be the kind of one–one mapping between brain regions and mental functions predicted by the view of the brain as a stimulus-driven device. Instead, given that brain dynamics are context-dependent and task-dependent, the same anatomical region may subserve different mental functions in different contexts, and the same mental function may be realized across a functionally connected network of distributed anatomical regions [13•,14••]. It follows that the explanatory heuristics of 'decomposition' and 'localization of function' [40] — differentiating a system into separable components and assigning specific functions to those components — are inadequate to characterize brain function when applied at the anatomical level. Nevertheless, with the increasing tendency to map cognitive functions onto functional connectivity networks [13•], the question arises of whether we should expect a one–one mapping from connectivity networks to cognitive functions. The answer may well be negative. As Pessoa [14••] has recently argued, given the shifting dynamical and context-dependent properties of networks, we should not anticipate a one–one mapping even when the network approach is adopted, for whether a given region belongs to a given network can change according to context, and hence the individuation of networks will not provide us with a list of non-overlapping regions. Thus, the difficulties involved in the brain-cognition mapping are not likely to be alleviated when connectivity networks, as opposed to anatomically distinct regions, are taken as the appropriate structural unit.

How should the study of the brain's functional organization proceed in the face of this complexity? One approach seeks to make more precise our understanding of the neural side of the brain-cognition mapping. For example, we need to go beyond the notion of 'functional connectivity,' taken as statistical correlation among the distributed regions affiliated with a given network, for such statistical dependencies, though revealing of co-activation patterns, do not provide information about the directions of influence between nodes of the network. Accordingly, researchers have proposed new methods for analyzing causal connectivity dynamics in order to elucidate further the functional organization of brain networks [13•,41,42].

A complementary approach is to refine our understanding of the cognitive function side of the mapping. Take, for example, attention. 'Attention' is standardly defined as referring to any process by which an organism selects some subset of the available information for enhanced processing [43]. Investigations of attention accordingly aim to identify the processes constitutive of such selection, such as orienting, filtering, searching, inhibition of distraction, and so forth, and to identify the neural systems that instantiate these processes [43–45]. In this view, 'attention' refers to a heterogeneous collection of distinct psychological and neural processes. Recently, however, a novel, unifying framework for understanding attention has been presented by philosopher Christopher Mole [46••]. He proposes that attention is not a distinct cognitive process or set of such processes, but rather a mode or manner in which multiple cognitive processes unfold dynamically in coordination with each other. His theory is stated at the level of the agent as a whole engaged in executing some task: a cognitive agent performs a task attentively if and only if that agent's performance displays 'cognitive unison.' This means that none of the cognitive processes that can serve to execute the task is occupied with something that does not serve the task, and in this way the processes jointly operate in the service of the task. An instructive analogy is that of unison in an orchestra. Just as there is no place in the orchestra where unison resides, so there is no place in the brain where attention is located. Rather, attention consists in the way that neural processes are dynamically coordinated with each other so as to enable and sustain the unison of the agent's cognitive processes in task performance. Although Mole does not relate his theory to neurodynamics, given that unison is an agent-level *mode* of processing rather than a particular neural process, it seems reasonable to suppose that cognitive unison is facilitated by the large-scale integration and dynamic coordination of oscillatory neural activity through mechanisms such as phase synchrony [28] and cross-frequency coupling [47,48•], which themselves are modes of neural activity and cannot be identified simply with the firings of particular populations of neurons. Thus the model of attention as cognitive unison can serve to refine our understanding of the agent-level and cognitive side of the brain-cognition mapping, and thereby cast new light on the ongoing effort to understand the dynamics of large-scale brain networks [49].

Neurophenomenology

Another complimentary approach, called 'neurophenomenology' [16], is to obtain detailed, first-person reports about moment-to-moment subjective experience in order to uncover information about dynamic brain activities relevant to understanding conscious mental processes [18,19,20••]. The working assumption of neurophenomenology is that first-person reports — especially from individuals either trained in the kind of metacognitive awareness cultivated in contemplative 'mindfulness' practices [50] (Lutz A, Jha AP, Dunne JD, Saron CD: **Investigating the phenomenological and neurocognitive matrix of mindfulness-related practices**, submitted for publication) or probed with refined methods for eliciting tacit experience [20••,51•] (or both) — can stand in a mutually constraining and illuminating relationship to cognitive-neuroscience evidence about the physiological processes sustaining moment-to-moment experience [16]. As discussed above, one of the main difficulties facing the brain-cognition mapping is the context-sensitivity of the relation between the two domains. Accordingly, neurophenomenology can be employed to produce more fine-grained first-person reports of the variability of moment-to-moment experience (such as fluctuations of attention, metacognition, emotion, bodily sensation, and memory) in a given individual from trial to trial in an experiment, and such reports can be used to reduce the noise of the neural signals, thereby providing a tighter coupling between the variability of the network dynamics and that of experience. Note that this proposal does not entail that seemingly random fluctuations must be considered useless or detrimental to the cognitive process under investigation. On the contrary, not all apparent random variability can be attributed to noise, and not all noise is useless or detrimental to the brain's performance, for noise may facilitate certain types of neuronal computations, depending on the context [52]. Rather, the neurophenomenological proposal is that collecting detailed phenomenological data about experiential variability can provide a crucial additional source of information and a methodological constraint for brain-cognition mappings. Note also that this proposal is compatible with a variety of neuroimaging modes in different experimental contexts. Thus, the neurophenomenological approach has been used, first, to differentiate novel EEG gamma-band phase synchrony patterns predictive of novel and distinct attentional states modulating visual perception [18]; second, to uncover distinct preictal experiences and predictive neurodynamical patterns in epileptic patients with implanted electrodes [53–55]; third, to characterize the default-mode network and executive system contributions to mind-wandering using fMRI [56,57]; and fourth, to link objective measures of brain activity with distinct strategies of metacognitive awareness using real-time fMRI neurofeedback [58], including relating such measures to reports of ongoing experience [59••,60]. In addition, neurophenomenology is currently being developed (fifth) to relate fine-grained information about the microdynamics of experiential cognitive processes to the trial-by-trial variability in neural processing as measured with intracerebral EEG [20••,61••], and sixth, to investigate the neural sources and temporal dynamics of spontaneous thought using fMRI (Ellamil M, Fox KCR, Dixon ML, Pritchard S, Todd RM, Thomspon E, Christoof K: **The origins of thought: neural sources and temporal dynamics of spontaneous thinking**, in preparation). Here we highlight the usefulness of neurophenomenology for investigating self-generated, spontaneous cognition [21].

Since 2006, there has been a dramatic increase in use of the term 'mind wandering' in psychology and cognitive neuroscience, suggesting to some researchers that we may have entered the 'era of the wandering mind' in the cognitive and brain sciences [62]. As Callard and colleagues [63] note, the initial stages of the empirical investigation of mind wandering, operationally defined as 'task unrelated thought,' took place in a research context still under the influence of the legacy of behaviorism; researchers mistrusted first-person reports and accordingly mainly focused on those cognitive functions that could be investigated using externally oriented tasks. It was within this context that neuroimaging researchers first noticed a set of distributed brain regions, now known as the 'default mode network' (DMN) [64•], that showed a pattern of co-activation during the resting state and a pattern of deactivation during externally oriented tasks. The subsequent view, however, that the DMN is the primary neural system activated at rest and that its activation mainly subserves mind wandering, has now come to be recognized as inadequate [21,62,63]. First, the spontaneous activity of the brain at rest cannot be reduced to DMN activity, for the whole brain exhibits highly organized, spontaneous activity when not occupied with an externally directed task [1,65]. Second, mind wandering recruits brain regions beyond those belonging to the DMN, notably regions belonging to executive networks [21,56]. Third, the purely negative, operational characterization of spontaneous, self-generated thought as 'task-unrelated' fails to distinguish among the variety of such forms of thought, many of which are goal-directed (such as autobiographical planning) [66]. For these reasons, determining which elements of spontaneous neural activity relate to which elements of spontaneous, self-generated thought remains an outstanding challenge [63]. Accordingly, recent work in this area has emphasized the need for both more phenomenologically nuanced conceptualizations of the various forms that spontaneous cognition can take, and for methods that can provide tighter couplings between the contents and temporal dynamics of spontaneous cognition and the activations of given brain regions and networks [21,62,63,66].

Recent studies indicate that neurophenomenology can help to meet these needs. Using real-time functional magnetic resonance imaging, Garrison, Brewer, and colleagues provided experienced meditators versus non-meditators with online feedback from their brain activity during an ongoing focused attention task [59••]. Not only were the subjective reports used to provide a guiding constraint on the specific region of the DMN — the posterior cingulate cortex (PCC) — that showed the strongest correlation with the momentary experience of mind wandering, but also the subjects were able volitionally to influence the activity of those regions after they had gained familiarity with these correlations. When instructed to volitionally decrease the feedback graph, meditators, but not non-meditators, showed significant deactivation of the PCC. This study indicates that experienced meditators can volitionally modulate their own brain activity, and thus suggests new ways to investigate the degree to which various cognitive strategies activate or deactivate hypothesized brain regions and networks in single subjects.

Similarly, in another study [67••], Allen and colleagues used the Error Awareness Task (EAT) combined with thought-probe elicited first-person reports of the subjective intensity, ruminative quality, and variability of mind-wandering experience in order to examine in detail the relation between metacognitive monitoring, on the one hand, and task performance and activity in specific DMN regions, on the other hand. By analyzing BOLD signal responses to the thought probes and the task, the contributions of the DMN and the executive and salience networks to task performance were dissociated, and novel evidence that variability in mind-wandering experience is related to greater metacognitive ability was provided.

As these studies illustrate, neurophenomenology provides both a method for examining the robustness of the correlation between the activation of a given region or network and a cognitive process, and a potential source of evidence for investigations concerned to move beyond patterns of co-activation to patterns of influence among brain regions, while also taking into account how such patterns may be modulated by volitional cognitive strategies and metacognitive awareness on the part of the subject [57,58,59••,60,61••] (Ellamil M, Fox KCR, Dixon ML, Pritchard S, Todd RM, Thomspon E, Christoof K: **The origins of thought: neural sources and temporal dynamics of spontaneous thinking**, in preparation).

Although the two studies just mentioned [59••,67••] used fMRI, a recent EEG study of mind wandering with experience sampling also dissociated the DMN from task-directed networks [68]. This study found that, during periods of mind wandering, there was significantly more neural phase synchrony between brain regions associated with the DMN, whereas during periods of visual task performance, there was significantly more neural phase synchrony within a task-specific brain network that shared some of the same brain regions. Although this study did not collect detailed phenomenological information about the experience of internally directed attention during mind wandering versus the experience of external, task-directed attention, collecting such information could prove beneficial for relating variabilities in the neural phase synchrony patterns to variabilities in subjective experience.

Conclusion

The contemporary view of the brain as a complex, self-organizing system with a rich variety of spontaneous, self-generated modes of activity confirms Kant's idea of the spontaneity of cognition. At the same time, this view brings to the fore the need for new concepts and methods to relate spontaneous brain activity to spontaneous cognition, including its conscious manifestations. Neurophenomenology is based on the recognition of this challenge and accordingly proposes a method for studying the variability and spontaneity of cognition and subjective experience in relation to the variability and spontaneity of neurodynamics. The hallmark of this method is to use fine-grained phenomenological information acquired from the first-person perspective to help illuminate the neural network dynamics that enable and sustain agent-level cognition. Although neurophenomenology is still in its infancy, recent results suggest a promising future.

Conflict of interest statement

Nothing declared.

Acknowledgement

S.F. and E.T. are supported by grants from the Social Sciences and Humanities Research Council of Canada.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Buszáki G: *Rhythms of the Brain*. New York: Oxford University Press; 2006, .

2. • Singer W: **Cortical dynamics revisited**. *Trends Cogn Sci* 2013, **17**:616-626.
A review highlighting recent theoretical and empirical work indicating that the brain is a complex, self-organized system with nonlinear dynamics whose neural networks provide a very high-dimensional state space for creating and maintaining information available to rapid, parallel search.

3. Tognoli E, Kelso JAS: **Enlarging the scope: grasping brain complexity**. *Front Syst Neurosci* 2014, **8**:122.

4. Northoff G: **Immanuel Kant's mind and the brain's resting state**. *Trends Cogn Sci* 2012, **16**:356-359.

5. Kant I: *Critique of Pure Reason*. . [Guyer P, Wood AW, Trans.] New York: Cambridge University Press; 1999, .

6. Hanna R: **Kant's theory of judgment**. In *The Stanford Encyclopedia of Philosophy.* Edited by Zalta EN. 2014 http://plato.stanford.edu/archives/sum2014/entries/kant-judgment/.

7. Maturana HR, Varela FJ: *Autopoiesis and Cognition*. Dordrecht: Reidel; 1980, .

8. Kelso JAS: *Dynamic Patterns: The Self-organization of Brain and Behavior*. Cambridge, MA: MIT Press; 1995, .

9. Friston K: **Life as we know it**. *J R Soc Interface* 2013, **10**:20130475.

10. Kant I: *Critique of the Power of Judgment*. . [Guyer P, Matthews E, Trans.] New York: Cambridge University Press; 2001, .

11. Juarrero Roqué A: **Self-organization: Kant's concept of teleology and modern chemistry**. *Rev Metaphys* 1985, **39**:107-135.

12. Thompson E: *Mind in Life: Biology, Phenomenology, and the Sciences of Mind*. Cambridge, MA: Harvard University Press; 2007, .

13. • Park H-J, Friston K: **Structural and functional brain networks: from connections to cognition**. *Science* 2013, **342**:1238411.
A review explaining how the mapping from functional neural networks to structural connections is degenerate (many–one), and describing a variety of formal, computational tools for investigating the emergence of dynamic functional networks.

14. •• Pessoa L: **Understanding brain networks and brain organization**. *Phys Life Rev* 2014, **11**:400-435.
A review arguing that although a network perspective should supplant the common strategy of understanding the brain in terms of individual regions, the mapping from neural networks to cognitive functions is many–many. Introduces the novel idea of 'diversity profiles' to describe the way that different brain regions participate in networks.

15. Cosmelli D, Lachaux J-P, Thompson E: **Neurodynamical approaches to consciousness**. In *The Cambridge Handbook of Consciousness.* Edited by Zelazo PD, Moscovitch M, Thompson E. Cambridge: Cambridge University Press; 2007:731-772.

16. Lutz A, Thompson E: **Neurophenomenology: integrating subjective experience and brain dynamics in the neuroscience of consciousness**. *J Conscious Stud* 2003, **10**:31-52.

17. Gallagher S, Zahavi D: *The Phenomenological Mind*. edn 2. London: Routledge Press; 2012, .

18. Lutz A, Lachaux J-P, Martinerie J, Varela FJ: **Guiding the study of brain dynamics using first-person data: synchrony patterns correlate with ongoing conscious states during a simple visual task**. *Proc Natl Acad Sci USA* 2002, **99**:1586-1591.

19. Cosmelli D, Thompson E: **Mountains and valleys: binocular rivalry and the flow of experience**. *Conscious Cogn* 2007, **16**:623-641.

20. •• Petitmengin C, Lachaux J-P: **Microcognitive science: bridging experiential and neuronal microdynamics**. *Front Hum Neurosci* 2013 http://dx.doi.org/10.3389/fnhum.2013.00617.
A neurophenomenological proposal to combine, first, the fine temporal and spatial resolution and single-trial precision of intracranial gamma band mapping with second, sophisticated interview methods for eliciting phenomenological information about the experiential microdynamics of cognitive processes.

21. Christoff K: **Undirected thought: neural determinants and correlates**. *Brain Res* 2012, **1428**:51-59.

22. Pessoa L: *The Cognitive–Emotional Brain: From Interactions to Integration*. Cambridge, MA: MIT Press; 2013, .

23. Bayne T: *The Unity of Consciousness*. New York: Oxford University Press; 2010, .

24. Dainton B: *Stream of Consciousness*. edn 2. London: Routledge; 2006, .

25. Barlow HB: **Single units and sensation: a neuron doctrine for perceptual psychology?** *Perception* 1972, **1**:371-394.

26. Kanwisher N: **Functional specificity in the human brain: a window into the functional architecture of the mind**. *Proc Natl Acad Sci USA* 2010, **107**:11163-11170.

27. Felleman DJ, van Essen DC: **Distributed hierarchical processing in the primate cerebral cortex**. *Cereb Cortex* 1991, **1**:1-47.

28. Varela F, Lachaux J-P, Rodriguez E, Martinerie J: **The brainweb: phase synchronization and large-scale integration**. *Nat Rev Neurosci* 2001, **2**:229-239.

29. Engel AK, Fries P, Singer W: **Dynamic predictions: oscillations and synchrony in top-down processing**. *Nat Rev Neurosci* 2001, **2**:704-716.

30. Gilbert CD, Sigman M: **Brain states: top-down influences in sensory processing**. *Neuron* 2007, **54**:677-696.

31. Grossberg S: **How does the brain build a cognitive code?** *Psychol Rev* 1980, **87**:1-51.

32. • Grossberg S: **Adaptive resonance theory: how a brain learns to consciously attend, learn, and recognize a changing world**. *Neural Netw* 2013, **37**:1-47.
A review of the current state of the art in Adaptive Resonance Theory, one of the earliest and most extensively developed theories of how the brain, by virtue of its autonomous and self-organizing dynamics, learns to categorize, recognize, and predict objects and events in a constantly changing world.

33. Rao RP, Ballard D: **Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects**. *Nat Neurosci* 1999, **2**:79-87.

34. Clark A: **Whatever next? Predictive brains, situated agents, and the future of cognitive science**. *Behav Brain Sci* 2013, **36**:1-24.

35. Hohwy J: *The Predictive Mind*. New York: Oxford University Press; 2013, .

36. Friston K: **Transients, metastability and neuronal dynamics**. *Neuroimage* 1997, **5**:164-171.

37. Freeman WJ, Holmes MD: **Metastability, instability, and state transitions in neocortex**. *Neural Netw* 2005, **18**:497-504.

38. • Kelso JAS: **Multistability and metastability: understanding dynamic coordination in the brain**. *Philos Trans R Soc Lond B Biol Sci* 2012, **367**:906-918.
A review of key evidence for multistable coordination dynamics in perception and action, and for metastability as a principle of coordination dynamics in the brain and cognition.

39. Carvalho GB, Damasio A: **The nature of feelings: evolutionary and neurobiological origins**. *Nat Rev Neurosci* 2013, **14**:143-152.

40. Bechtel W, Richardson RC: *discovering Complexity: Decomposition and Localization as Strategies in Scientific Research*. Princeton, NJ: Princeton University Press; 1993, .

41. Bressler SL, Seth AK: **Wiener–Granger causality: a well established methodology**. *Neuroimage* 2011, **58**:323-329.

42. Bedo N, Ribary U, Ward LM: **Fast dynamics of cortical functional and effective connectivity during word reading**. *PLoS One* 2014 http://dx.doi.org/10.1371/journal.pone.0088940.

43. Ward L: **Attention**. *Scholarpedia* 2008, **3**:1538 http://dx.doi.org/10.4249/scholarpedia.1538.

44. Corbetta M, Shulman GL: **Control of goal-directed and stimulus-driven attention in the brain**. *Nat Rev Neurosci* 2002, **3**:201-215.

45. Posner MI, Rothbart MK: **Research on attention networks as a model for the integration of psychological science**. *Annu Rev Psychol* 2007, **58**:1-23.

46. •• Mole C: *Attention is Cognitive Unison*. New York: Oxford University Press; 2011, .
A philosophical study arguing that attention cannot be explained by specifying the neurocognitive processes that constitute any given instance of attention, because whether an agent is attentive depends not on the presence of such processes but rather on whether the processes taking place — whatever they are — operate in unison in the service of the agent's task.

47. Canolty RT, Knight RT: **The functional role of cross-frequency coupling**. *Trends Cogn Sci* 2010, **14**:506-515.

48. • Szczepanski SM, Crone NE, Kuperman RA, August KI, Parvizi J, Knight RT: **Dynamic changes in phase-amplitude coupling facilitate spatial attention control in fronto-parietal cortex**. *PLoS Biol* 2014, **12**:e1001936.
A study investigating how human frontal and parietal cortices use neural oscillations to control visual spatial attention. The trial-by-trial performance of the subjects in a spatial cuing task was predicted by changes in the coupling strength between delta/theta phase and high gamma amplitude oscillations recorded from subdural electrodes. The authors conclude that such cross-frequency coupling serves to coordinate information within and perhaps between frontal and parietal areas during allocation of visuospatial attention.

49. Bressler SL, Menon V: **Large-scale brain networks in cognition: emerging methods and principles**. *Trends Cogn Sci* 2010, **14**:277-290.

50. Lutz A, Slagter HA, Dunne JD, Davidson RJ: **Attention regulation and monitoring in meditation**. *Trends Cogn Sci* 2008, **12**:163-169.

51. • Petitmengin C, Remillieux A, Cahour C, Carter-Thomas S: **A gap in Nisbett and Wilson's findings? A first-person access to our cognitive processes**. *Conscious Cogn* 2013, **22**:654-669.
An experiment showing that although we are usually unaware of our decision processes, we can gain cognitive access to them through the specific mental acts of retrieving the moment of decision and redirecting attention to the decision process, when these acts are elicited by the skilled guidance of an interview. This method can be used more generally to elicit detailed phenomenological information about the variability of experiential microcognitive processes, and such information can be used to uncover information about the variability of neurocognitive processes, according to the method of neurophenomenology (see also [20••]).

52. McDonnell MD, Ward LM: **The benefits of noise in neural systems: bridging theory and experiment**. *Nat Rev Neurosci* 2011, **12**:415-425.

53. Petitmengin C, Baulac M, Navarro V: **Seizure anticipation: are neurophenomenological approaches able to detect preictal symptoms?** *Epilepsy Behav* 2006, **9**:298-306.

54. Petitmengin C, Navarro V, Le Van Quyen M: **Anticipating seizure: pre-reflective experience at the center of neurophenomenology**. *Conscious Cogn* 2007, **16**:746-764.

55. Amor F, Baillet S, Navarro V, Adam C, Martinerie J, Le Van Quyen M: **Cortical local and long-range synchronization interplay in human absence seizure initiation**. *Neuroimage* 2009, **45**:950-962.

56. Christoff K, Gordon AM, Smallwood J, Smith R, Schooler J: **Experience sampling during fMRI reveals default network and executive system contributions to mind wandering**. *Proc Natl Acad Sci USA* 2009, **106**:8719-8724.

57. Hasenkamp W, Wilson-Mendenhall CD, Duncan E, Barsalou LW: **Mind wandering and attention during focused attention meditation: a fine-grained temporal analysis of fluctuating cognitive states**. *Neuroimage* 2012, **59**:750-760.

58. McCaig RG, Dixon ML, Kermatian K, Liu L, Christoff K: **Improved modulation of rostrolateral prefrontal cortex using real-time fMRI training and meta-cognitive awareness**. *Neuroimage* 2012, **55**:1298-1305.

59. •• Garrison KA, Scheinost D, Worhunsky PD, Elwafi HM, Thornhill TA IV, Thompson E, Safon C, Desbordes G, Kober H, Hampson M, Gray JR, Constable RT, Papademetris X, Brewer JA: **Real-time fMRI links subjective experience with brain activity during focused attention**. *Neuroimage* 2013, **81**:110-118.
This study used real-time fMRI neurofeedback to assess the coupling between a real-time objective measure of brain activity in the PCC and momentary subjective experience during a focused attention task in experienced meditators versus non-meditators. When instructed to volitionally decrease the feedback graph, meditators, but not non-meditators, showed significant deactivation of the PCC. This study indicates that experienced meditators are able to volitionally modulate their brain activity, thereby suggesting new ways to investigate the degree to which various cognitive strategies activate or deactivate hypothesized brain regions and networks in single subjects.

60. Garrison KA, Santoyo JF, Davis JH, Thornhill TA IV, Kerr CE, Brewer JA: **Effortless awareness: using real-time neurofeedback to investigate correlates of posterior cingulate cortex activity in meditators' self-report**. *Front Hum Neurosci* 2013, **7** http://dx.doi.org/10.3389/fnhum.2013.00440 Article 440.

61. •• Bagdasaryan J, Le Van Quyen M: **Experiencing your brain: neurofeedback as a new bridge between neuroscience and phenomenology**. *Front Hum Neurosci* 2013, **7** http://dx.doi.org/10.3389/fnhum.2013.00680 Article 680.
Proposes that neurofeedback is well suited for neurophenomenological efforts to relate the variability of first-person experience to the variabilty of neural network dynamics, and thereby provides a theoretical justification for the kind of research pursued in [57,58,59••].

62. Callard F, Smallwood J, Golchert J, Margulies DS: **The era of the wandering mind? Twenty-first century research on self-generated mental activity**. *Front Psychol* 2013, **4** http://dx.doi.org/10.3389/fpsyg.2013.00891 Article 891.

63. Callard F, Smallwood J, Margulies DS: **Default positions: how neuroscience's historical legacy has hampered investigation of the resting mind**. *Front Psychol* 2012, **3** http://dx.doi.org/10.3389/fpsyg.2012.00321 Article 321.

64. • Buckner RL: **The serendipitous discovery of the brain's default network**. *Neuroimage* 2012, **62**:1137-1145.
An informative account of the discovery of the brain's default-mode network.

65. Leopold DA, Maier A: **Ongoing physiological processes in the cerebral cortex**. *Neuroimage* 2012, **62**:2190-2200.

66. Christoff K: **Thinking**. In *The Oxford Handbook of Cognitive Neuroscience*. Edited by Oschner KN, Kosslyn SM.. **The Cutting Edges**. Oxford: Oxford University Press; 2013:318-333.

67. •• Allen M, Smallwood J, Christensen J, Gramm D, Rasmussen B, Jensen CG, Roepstorff A, Lutz A: **The balanced mind: the**

variability of task-unrelated thoughts predicts error monitoring. *Front Hum Neurosci* 2013, **7** http://dx.doi.org/10.3389/fnhum.2013.00743 Article 743.

This study examined the influence of first-person reported subjective intensity, ruminative quality, and variability of mind wandering on response inhibition and monitoring, using the EAT. By analyzing BOLD signal responses to thought probes and the EAT, the contributions of the default-mode, executive, and salience networks to task performance were dissociated, and novel evidence that variability in mind-wandering experience is related to greater metacognitive ability was provided.

68. Kirschner A, Kam JWY, Handy CT, Ward LM: **Differential synchronization in default and task-specific networks of the human brain**. *Front Hum Neurosci* 2012, **6** http://dx.doi.org/10.3389/fnhum.2012.00139 Article 139.