Natural moment-to-moment signal variability and stochastic facilitation

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We have recently provided an Opinion article (The benefits of noise in neural systems: bridging theory and experiment. *Nat. Rev. Neurosci.* **12**, 415–426 (2011))[1] that highlights the benefits of stochastic resonance to information processing.

We thank Garrett, McIntosh and Grady for their very interesting correspondence (Natural moment-to-moment signal variability in the human brain can inform models of stochastic facilitation. *Nature Rev. Neurosci.* 7 Sept 2011 (doi:10.1038/nrn3061-c1))[2], which allows us to explore some additional ideas about stochastic facilitation. They point out that recent research has found correlations between higher variability of signals and relatively enhanced function in a variety of tasks[2]. They comment that this work may inform future models of stochastic facilitation. Although we find this to be an intriguing possibility, we emphasize that such correlations do not, in isolation, provide strong evidence for stochastic facilitation. Higher variability could also be a consequence of the increased signal content that is necessary for enhanced function or an increased ability of the brain to explore its own state space (that is, the entire set of states that a dynamical system can enter, defined by the ranges of values that its defining variables can assume), as argued by Garrett *et al*[3]. Although state-space exploration can be facilitated by stochastic noise[4], and indeed other work by one of the commenting authors has shown this in brain network simulations[5], it can also be facilitated by other mechanisms[6]. Indeed, the state space of the maturing brain is likely to increase during development and then decline during ageing, so that the increased variability might be seen as simply the consequence of an ability to completely exploit the existing state space.

Moreover, as pointed out in our article, signals can seem as random as noise; as an analogy, information transmission in Gaussian channels is maximized by a signal that can be modelled as a Gaussian random variable[7]. The argument that what some consider to be noise may actually contain predictive information is similar to that made regarding 'error variance' in human experimental psychology during the 1990s in the context of nonlinear dynamical systems theory (chaos)[8]. Showing that this is true of the functional MRI blood oxygen level-dependent (BOLD) signal is certainly useful and important but it is a somewhat different point from showing that stochastic noise, which contains no predictive power whatsoever on its own, can facilitate a neural computation.

Relative increases in signal variability over the lifespan or in other circumstances (as measured, for example, by multiscale entropy) might also be explained as a consequence of more complicated neural processing rather than as stochastic facilitation. Although what is measured can always be modelled as a stochastic variable, it may be 'stochastic' only in the sense that the underlying detailed processing is unknown (and possibly unknowable in the near term).

Consider, for example, the central processing unit of a von Neumann computer. If one recorded the amount of heat that was produced by the chip during various computations, one would see greater heat variability when the chip was computing a wavelet transform on a set of epochs of a time series than when it was idling, waiting for input. It should not be concluded that the seemingly greater 'noisiness' of the heat signature reflects stochasticity. Variability and noise are not the same thing. Moreover, if the variability arises from the complexity of the computations rather than from a stochastic element of the computations themselves (or what we call stochastic facilitation, in which some randomness is required as a part of efficient computation) then this is not what we mean by stochastic facilitation.

If stochastic facilitation is to be identified based on neuroimaging work in which increased variability is observed, it would be necessary to show that the variability is actually arising from some element of randomness in the computations rather than simply from computational complexity (that is, periods of more intense or less intense activity because of variable computational demands).

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