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Structures of Neural Correlation and How They Favor Coding

Highlights

- Neural noise correlations have stimulus-dependent structure in retina and cortex
- Analysis of neural data demonstrates that this structure improves visual coding
- Response models capture the emergence of this structure from circuit properties
- Neural coding models indicate that it can affect coding strategies qualitatively

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In Brief

Coding in the brain suffers from the variability of neural responses. Using experiment and theory, Franke et al. show that this "noise" comes with a particular structure, which emerges from circuit properties and which counteracts the harmful effect of variability.

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Structures of Neural Correlation and How They Favor Coding

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SUMMARY

The neural representation of information suffers from "noise"—the trial-to-trial variability in the response of neurons. The impact of correlated noise upon population coding has been debated, but a direct connection between theory and experiment remains tenuous. Here, we substantiate this connection and propose a refined theoretical picture. Using simultaneous recordings from a population of direction-selective retinal ganglion cells, we demonstrate that coding benefits from noise correlations. The effect is appreciable already in small populations, yet it is a collective phenomenon. Furthermore, the stimulus-dependent structure of correlation is key. We develop simple functional models that capture the stimulus-dependent statistics. We then use them to quantify the performance of population coding, which depends upon interplays of feature sensitivities and noise correlations in the population. Because favorable structures of correlation emerge robustly in circuits with noisy, nonlinear elements, they will arise and benefit coding beyond the confines of retina.

INTRODUCTION

There is a long history of studies of the representation of information by single neurons, but the investigation of coding by populations of neurons is far less advanced. High dimensionality makes the problem difficult: on the experimental side, because access to the simultaneous activity of an entire population is necessary; on the theoretical side, because the way in which information is coded in this simultaneous activity has to be elucidated. The problem is high dimensional, in particular, since different neurons can process their inputs in different ways and since their outputs can be correlated. Coding in the face of these two aspects—the diversity of cell types and neural response properties, and the correlation in neural activity—is the topic of the present paper.

Neural noise is a theme that runs through any discussion of neural coding. In the simplest case, the noise in the output of a neuron is independent from that in other neurons. Noise then makes the output of each neuron less precise and thereby harms the coding performance. In contrast to this idealized case, many brain areas display "noise correlation," i.e., correlation in the variability of the output of a population of neurons in response to a given stimulus (Hatsopoulos et al., 1998; Mastronarde, 1989; Ozden et al., 2008; Perkel et al., 1967; Sasaki et al., 1989; Zohary et al., 1994; Shlens et al., 2008; Usrey and Reid, 1999; Vaadia et al., 1995; Bair et al., 2001; Fiser et al., 2004; Kohn and Smith, 2005; Smith and Kohn, 2008; Lee et al., 1998; Ecker et al., 2010; Graf et al., 2011; Goris et al., 2014; Lin et al., 2015). The problem now becomes higher dimensional: beyond the degree of noise in each neuron, one has to be concerned with all the other quantities that describe the statistical relations among neurons. In other words, when examining the impact of noise on coding, one has to take into account not only the magnitude of the noise, but also its structure.

In past years, a number of theoretical proposals on the way in which noise correlation may impact coding have been put forth (Johnson, 1980; Vogels, 1990; Oram et al., 1998; Abbott and Dayan, 1999; Panzeri et al., 1999; Sompolinsky et al., 2001; Wilke and Eurich, 2002; Romo et al., 2003; Golledge et al., 2003; Pola et al., 2003; Averbeck and Lee, 2003, 2006; Shamir and Sompolinsky, 2004, 2006; Averbeck et al., 2006; Josić et al., 2009; Ecker et al., 2011; Hu et al., 2014; da Silveira and Berry, 2014). Many of these have argued that noise correlation is detrimental to the coding performance, and this statement was, for some time, taken as a rule of thumb. More recently, some studies have demonstrated that correlation can be beneficial to neural coding, depending upon its structure (Ecker et al., 2011; Hu et al., 2014; da Silveira and Berry, 2014; Lin et al., 2015; see also Wilke and Eurich, 2002; Moreno-Bote et al., 2014). In most cases, however, a model of the structure of correlation was assumed, and its consequences were derived: there are, as yet, very few direct demonstrations of the role of correlation in coding, as these require