Homeostatic gain modulation drives changes in heterogeneity expressed by neural populations

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Abstract:

Diversity exists all throughout biology where it plays an important role in maintaining robustness and stability [1]. The same is true of the brain [2], as has become increasingly apparent in recent years with the accumulation of datasets of unparalleled resolution [3,4]. These datasets show that heterogeneity in the brain is widespread, spanning cells, circuits and system dynamics, marking it as an unavoidable component of neuronal composition. Recent experiments found that decline in biophysical heterogeneity amongst neurons may accompany pathological states such as epilepsy [5]. While heterogeneity has been linked to stability, robustness and increased computational potential [2,6], loss of biophysical diversity was found to be conducive to the onset of seizure-like activity [5], suggesting an important functional role. Despite this, how such changes in heterogeneity arise remains unknown. Oftentimes considered to be a static metaparameter resulting from solely genetic disposition, heterogeneity is, in fact, a highly dynamic property of biological networks arising from various sources [3]. Here, we consider this through the lens of intrinsic plasticity [7,8]. This form of homeostatic gain modulation, wherein neurons alter their excitability in response to their past activity and received input, allows heterogeneity expressed by neural populations to fluctuate in time. Using a network of Poisson neurons endowed with intrinsic plasticity, we combine analytical and numerical approaches to measure the effect of input statistics on the excitability of individual cells, and how this

translates into changes in network heterogeneity at the population scale. We find that heterogeneity is sensitive to features influencing the input statistics to the neurons, such as network in-degree, mean connectivity weight and impinging spike rate. Increased variability in these features results in high amplitude fluctuations in the membrane potential, promoting heterogeneity and supporting its retention when induced by stimulation. Conversely, the level of heterogeneity is reduced if these statistics are stereotyped. The reduction in the cell-to-cell membrane potential variability homogenizes the system excitability, resulting in unstable dynamics. This bidirectional effect could underlie the pathological alterations to heterogeneity observed in epilepsy. Taken together, understanding how input statistics affect neuronal network heterogeneity may provide key insights into brain function resilience, and the manipulation of neural diversity through intrinsic plasticity.

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