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Assessment of Hippocampal and Autonomic Neural Activity by Point Process Models

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Abstract

The development of statistical models that accurately describe the stochastic structure of neural oscillations is a fast growing area in quantitative research. In developing a novel statistical paradigm based on Bayes' theorem and the theory of point processes, we focused our recent research on two applications. The first studies how hippocampal neural activity represents and transmits information, whereas the second is aimed at characterizing activity of the central autonomic network as involved in cardiovascular control.

Hippocampal Spiking Activity

Neural spike train decoding algorithms are mathematical methods used to estimate a biological signal from the spiking activity of a single neuron or group of neurons. In the rat hippocampus, a region of the brain important for long-term memory formation, pyramidal neurons known as place cells form spatial receptive fields as the animal forages in its environment. Decoding studies of this system have shown that it is possible to estimate with reasonable accuracy the position of the animal in its environment from the ensemble spiking activity of place cell neurons. Our research centers on how individual and ensembles of neurons encode information about relevant biological stimuli, and uses point process models of spatial information representation by neurons in the rat hippocampus. We have applied the Bayesian algorithms to CA1 place cells recordings from rats foraging in an open environment. We used our models to estimate the dynamics of both the spatial receptive field (spatial intensity function) and the interspike interval structure (temporal intensity function) of neural spike trains on a millisecond time scale. We further implemented Bayesian decoding algorithms for position estimation. Using only the recorded spiking activity of 30 cells, the most refined paradigm is now able to obtain position estimates with errors as small as 5 cm [1]. Current work is focusing on Bayesian models with more complex history dependence, multivariate interactions among cells, neural plasticity in ensemble neural spike train decoding, as well as characterizing transition probabilities between ‘up’ and ‘down’ states in a neuronal population.

Autonomic Modulation of the Heart

Heart rate (HR) and heart rate variability (HRV) are important dynamic measures of the influence of the autonomic nervous system on the heart. Heart rate is traditionally estimated as the average of the reciprocal of the *R*-*R* intervals within a specified time window, or as the number of *R* –wave events (heart beats) per unit time on the electrocardiogram (ECG). We have derived new definitions of HR and HRV based on an explicit point process Bayesian probability model for heart rate under the assumption that the stochastic properties of the *R*-*R* intervals are governed by an inverse Gaussian renewal model. We estimate the time-varying inverse Gaussian parameters by either local maximum likelihood [2] or an adaptive point process algorithm [3], and assess model goodness-of-fit by Kolmogorov-Smirnov tests based on the time-rescaling theorem. These models give a more physiologically sound representation of the stochastic structure in heart beat generation than those provided by current definitions and analysis methods. We have validated our paradigm with data from healthy subjects during sleep, meditation, a tilt protocol, and under autonomic blockade, as well as from subjects with congestive heart failure. Importantly, we have also devised a novel approach combining our estimates with fMRI recordings in order to identify the human brain correlates of autonomic modulation for various stimuli and physio-pathological states. Current work is focusing on more complex representations of the probability function, incorporating the point process framework into models of cardiovascular control and autonomic regulation, with inclusion of other cardiovascular variables such as arterial blood pressure, central venous pressure and respiration. Overall, our results confirm that our point process framework provides new quantitative indices that could have important implications for research studies of cardiovascular and autonomic regulation, and for HR monitoring in clinical settings.

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