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Characterizing multiple-unit activity in the anterior cingulate cortex during choice behavior as a stochastic nonlinear process

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Successful decision-making requires an ability to monitor contexts, actions and outcomes, functions in which the anterior cingulate cortex (ACC) plays a critical role. There is accumulating evidence that the transient organization of neurons into dynamic ensembles and the sequential transitions among them may form the basis for cortical information processing [1-3]. Recently, we analyzed the population activity obtained from multiple single-unit recordings from the rat ACC during performance of an ecologically valid decision making task [2]. We showed that ensembles of neurons move through different coherent and dissociable states as the cognitive requirements of the task change. This organization into distinct network patterns with respect to firing rate changes broke down on trials with numerous behavioral errors, especially at choice points of the task. So far, in this and other studies, state spaces were examined that were *direct* representations of the multiple-unit activity (MUA) with dimensions directly corresponding to the instantaneous firing rates of all simultaneously recorded units. These spaces were then visualized using dimensionality reduction techniques like metric multi dimensional scaling and analyzed using multivariate statistics like linear discriminant functions [2,3]. However, there is also evidence that, for instance temporary synchrony among neurons down to the millisecond level and locked to specific behavioral events [4], plays an important role in neural information processing. These highly non-stationary properties of the MUA time series are not or only implicitly contained in previous state space approaches, a problem which some groups started to address [5]. Therefore, the temporal dynamics of ACC neurons and their functioning as an integrated network are still poorly understood. A more in-depth understanding might be achieved by new algorithms that fuse statistical learning with nonlinear time series analysis methods. Here, we propose a new *model-free* multivariate nonlinear stochastic time series algorithm for the analysis of those simultaneous multiple single-unit recordings. It produces a low-dimensional state space that is optimal with regards to several dynamical properties of the multiple recorded units. Our results show that not only successful choice behavior, as it was demonstrated in [2], but also the *incorrect* choice behavior in challenging situations can be visually and effectively characterized as attracting sets in a suitable coordinate map, but with important differences to the state space characterization of MU activity during *correct* choice behavior. These methods also suggest ways to accurately predict behavior based on the state space trajectories obtained from the neural ensemble dynamics.

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