Finding Directional Movement Representations in Motor Cortical Neural Populations using Nonlinear Manifold Learning

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Abstract: While state-of-the-art technology in neural motor prostheses has led to clinical applications for paralyzed patients, it has also opened a new avenue to understanding motor cortical neural systems by providing chronic and simultaneous recordings of multi-channel neural activity and complex natural behavior. In order to investigate these neural motor data, however, one must deal with high-dimensional, correlated, and possibly nonlinear neural population codes. To address these challenges, we propose using a nonlinear dimensionality reduction method to investigate the representation of movement in neural firing patterns. Using this method allows us to find a low-dimensional embedding space of high-dimensional nonlinear neural manifolds. Specifically, a class of Isomap methods was used to find a low-dimensional representation of spatio-temporal neural firing patterns. These methods were applied to directional movement data recorded during an experiment in which a primate reached targets in a radial center-out configuration. Through these methods, the dimensionality of the neural population could be reduced approximately by 33% (e.g. from 61 neuronal units to 20-dimensional manifolds). On the lower-dimensional (2D or 3D) manifolds, the temporal patterns corresponding to each directional movements presented affine characteristics in their directions and evolutionary patterns. These patterns were smoother and clearer via the nonlinear methods than linear approaches such as the principal component analysis. The key advantage of our approach is that it provides an unsupervised way to obtain low-dimensional representations without explicit models relating neural firing patterns with motor parameters. In fact, we were able to cluster the spatio-temporal neural firing patterns through the Isomap methods without movement information. The resulted clusters could be well paired with each movement direction, and we found only 2.5% mismatches between firing patterns and corresponding directions. Consequently, the proposed approach creates low-dimensional feature spaces of spatio-temporal neural firing patterns that can provide useful information for neural population coding of movements.