Isotropic preferred-torque distributions explain anisotropic preferred-direction distributions and population vector/reach direction relationships

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A simple model describing the relationship between neural activity in MI and corresponding two-dimensional arm motion in the horizontal plane is examined, wherein contributions to torques \( (\tau_1, \tau_2) \) at both shoulder and elbow by each neuron are assumed proportional to the firing rate. Individual cell activity is assumed to increase as the direction of the \( (\tau_1, \tau_2) \)-vector approaches that of the corresponding (constant) torque-per-firing-rate vector \( (u_j, v_j) \) generated by the jth neuron. For example, if cosine tuning is assumed on the \( (\tau_1, \tau_2) \)-plane, and a continuous isotropic gaussian distribution \( N(u,v) \) is assumed, then a neuron’s activity is given by

\[
r_j = \frac{8\sqrt{\pi}}{N_{\text{tot}}\rho} \sqrt{\tau_1^2 + \tau_2^2} \cos(\phi_j - \theta_j) \]

where \( \phi = \tan^{-1}(\tau_2 / \tau_1) \), \( \theta_j = \tan^{-1}(v_j / u_j) \), and \( N_{\text{tot}} \) are the total number of neurons in the distribution and the r.m.s. norm of the \( (u,v) \)-vector. Due to torques required to decelerate the arm after reaching peak velocity, cell activity as a function of reach direction tends to be bimodal (maxima 180 degrees apart) when the ratio of frictional to inertial torques is small. Such bimodality has been observed, particularly when monkeys move manipulanda of appreciable mass (cf. [1]). In the presence of substantial viscous friction, activities become unimodal, preferred directions (PDs) are meaningful, and population vectors as defined by Georgopoulos can be constructed. Applied to linear reaching tasks originating from a common point, results show (1) systematic deviations between reach directions and population vectors (Fig.1), (2) large variations of population vector magnitudes with reach directions (Fig.2), and (3) anisotropic distributions of PDs, all of which are very similar to those observed by Scott et al. [2]. Because the assumed distribution \( N(u,v) \) is isotropic, it is clear that anisotropic distributions of PDs can be artifacts of the task set, and not necessarily fundamental properties of neural ensembles. Using synthetic ensembles with torque-tuning properties selected randomly from \( N(u,v) \), the pseudo-inverse method was employed to reconstruct torque trajectories from cell activities, resulting in sets of filter coefficients that were compared against the known synthetic cell properties. These experiments suggest that in order to extract approximate torque-tuning characteristics of neural ensembles, more than 1000 neurons are probably required.

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References