Animals are often faced with uncertainty about which actions will be the most beneficial. When presented with two possible movements the nervous system could withhold planning; however, previous studies have suggested that monkeys represent plans to both options simultaneously (Cisek & Kalaska, Neuron, 2005) or alternate plans between locations (Horwitz & Newsome, J. Neurophys., 2001). Presumably, these strategies allow for faster movements than not planning at all, though the behavioral benefit of these strategies has not been explored. Here, we recorded from ensembles of neurons to directly observe which strategy is adopted when a monkey must make fast and accurate reaches given uncertainty about target location. We trained monkeys to perform three versions of a delayed-reach task. In the first version (delayed-reach task), one target was presented during a delay period, after which the monkey was rewarded for a reach to that target. The second version (distractor task) was nearly the same as the first, but a distractor (different color) was presented in the location opposite the target. In the third version (delayed-reach task with ambiguous delay) two possible targets (same color) were presented during the delay period, after which the correct target was identified (by a change of color). All three trial types were interleaved.

Simultaneous responses of 82-102 neurons were recorded using a microelectrode array implanted in dorsal premotor cortex (PMd), and we used linear methods such as factor analysis and principal components analysis to reduce the dimensionality of the neural responses. Using the first few dimensions of the low-D projections of these responses, we examined single-trial trajectories representing the evolution of delay-period activity. These plan trajectories suggested that on some trials monkeys alternated planning to the two possible reach goals, planned reaches to only one of the targets, or formed plans not directly corresponding to any of the targets. To increase confidence that these results were due to coordinated neural activity rather than spurious spiking noise, we computed the fraction of each trajectory's path that lay closer to the target zones than to the baseline (no plan) zone. Bootstrap analysis revealed far greater amounts of plan trajectory residing close to the single-target planning zones than expected by chance (p<0.001, comparison with trial-shuffled data, three datasets). To our knowledge this is the first evidence that in a task with 2 target options, a variety of strategies is used on different trials.

Fig. 1. 3D representation of data in factor analysis space. (a) Delayed-reach task. Green points represent plans to target 1 (t1); blue points represent plans to target 2 (t2); red points represent neural state at target onset. Gray lines are plan trajectories for all delayed-reach trials. Two trajectories are highlighted in green/blue as examples of typical plan trajectories for t1/t2. (b) Delayed-reach task with ambiguous delay period. One example trajectory is shown, illustrating a type of complex plan dynamics seen during the 400 ms delay period. Blue/green/red points as in (a).

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