Cortical Representation of Bimanual Movements: Patterns of Interference

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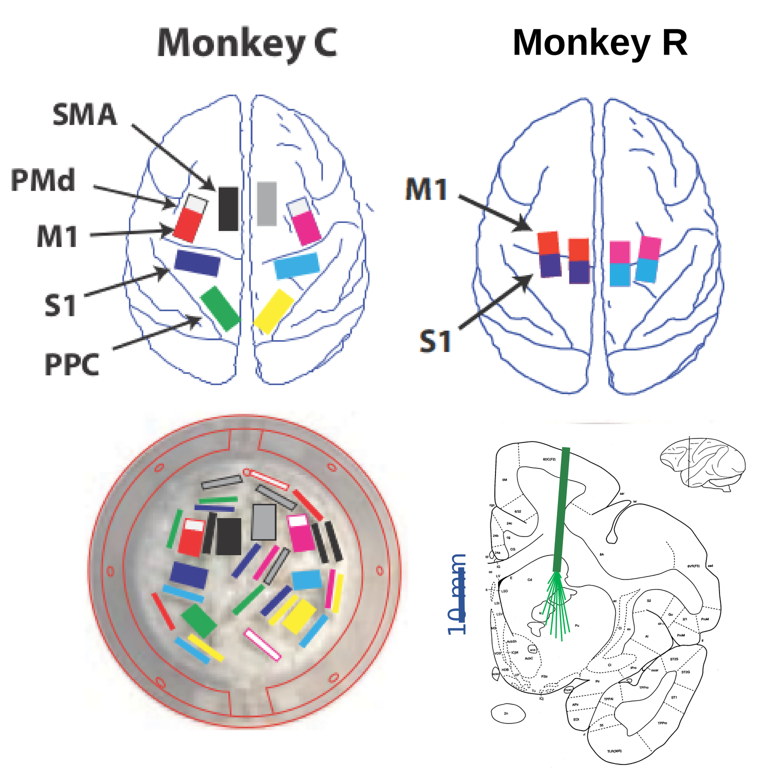
Abstract

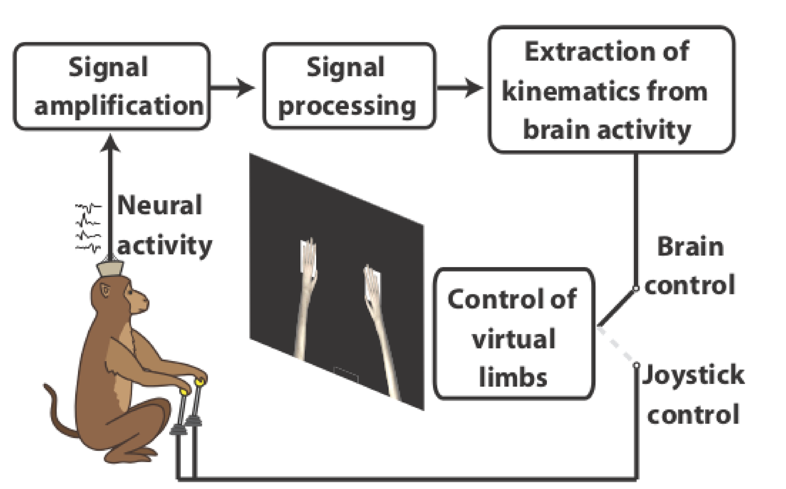
Independent movements by two arms, such as reaching simultaneously to two different targets, are prone to patterns of interference. For example, it is easier to move two arms in the same direction than to make different movements with the right and left arm. The underlying neural mechanisms are poorly understood. Here we show that cortical neuronal ensembles in the primary motor cortex (M1) and supplementary motor area (SMA) exhibit distinct patterns of activity that represent patterns of interference during bimanual reaching movements. Rhesus monkeys performed a bimanual joystick centerout task with four possible target locations for each hand. We found that clear patterns of movement interference existed during the task, and this was dependent on target configuration. Using bilateral, multielectrode implants, we recorded from several hundred neurons in M1 and SMA. We observed enhanced ensemble modulations during bimanual versus unimanual movements. Moreover, the degree of bimanual interference had a clear effect on neuronal patterns, particularly in SMA, where neurons were modulated more for more dissimilar movements with two arms. While the movements of each arm were represented by both cortical hemispheres, the distribution of activity across the hemispheres reflected the interference, as well. We suggest that both coordinated and independent bimanual movements are represented in a highly distributed fashion by cortical ensembles. This dynamic and highly plastic representation underlies what is usually called "cortical body schema".

Experimental Design

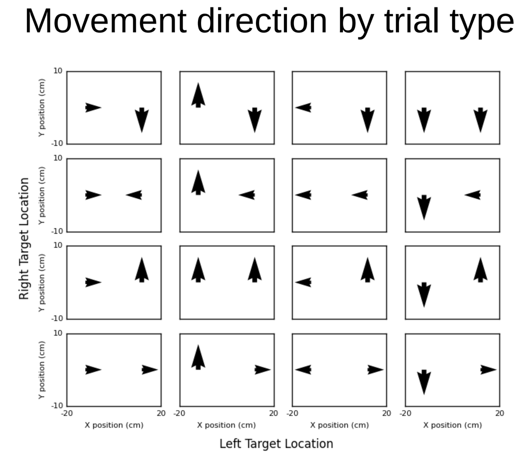


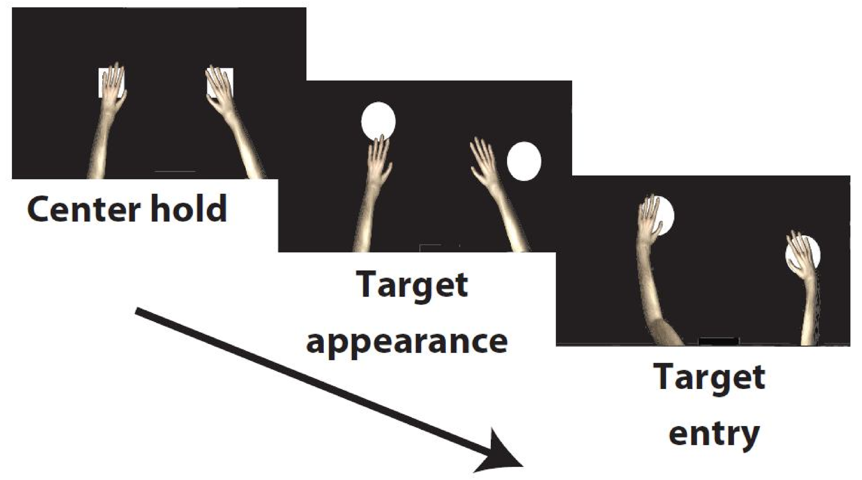
Channel Count = 768

Channel Count = 1372



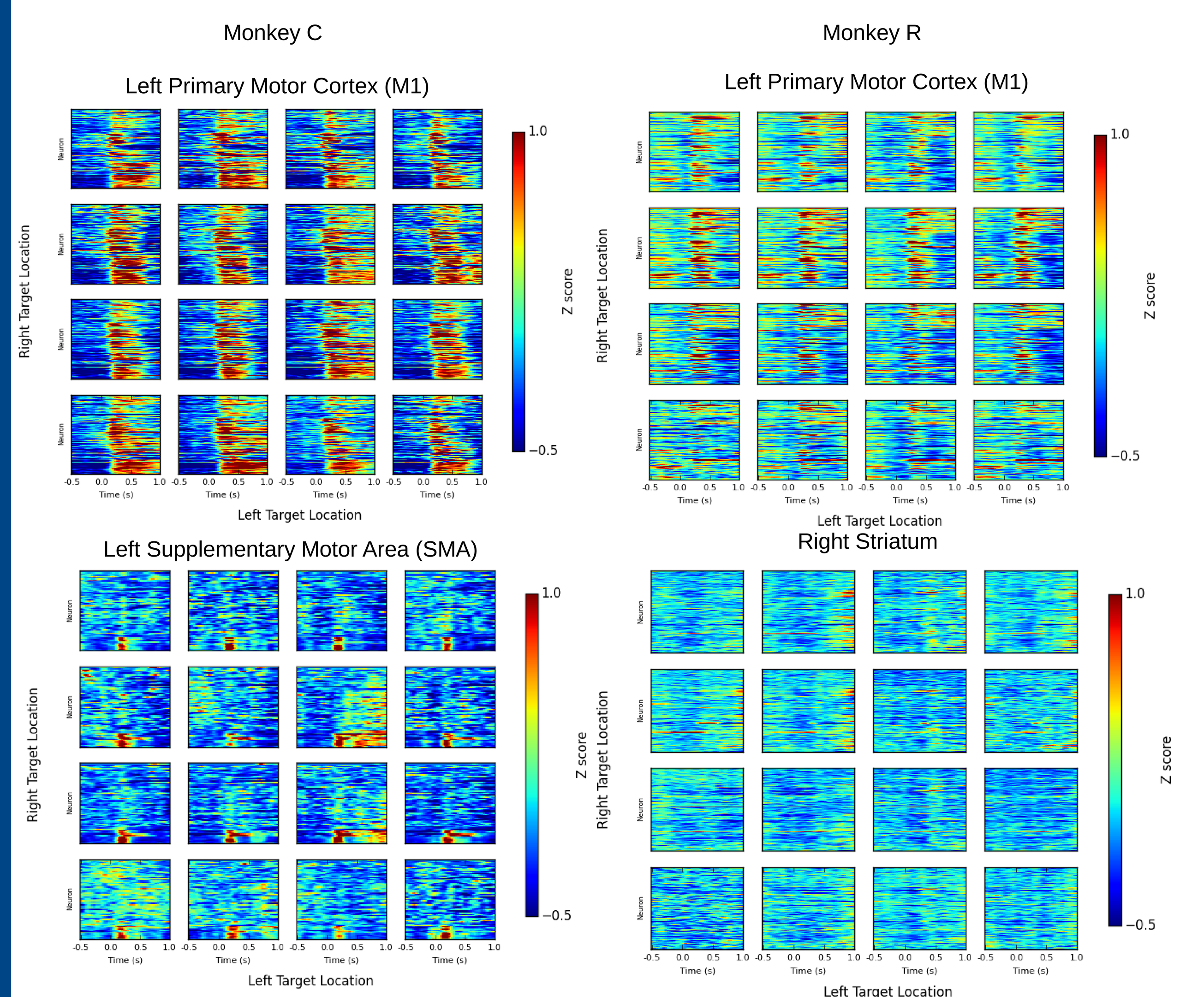
Movement direction by trial type





Results

Neural Ensembles in M1, SMA and Striatum show different activities during bimanual movements



$$Firing\ Rate = ax_i + by_i + cx_c + dy_c + e + \epsilon$$

x_i, y_i are cursor velocities of the arm ipsilateral to the recorded neuron

x_c, y_c are cursor velocities of the arm contralateral to the recorded neuron

e is the offset (~ mean firing rate), ϵ is error

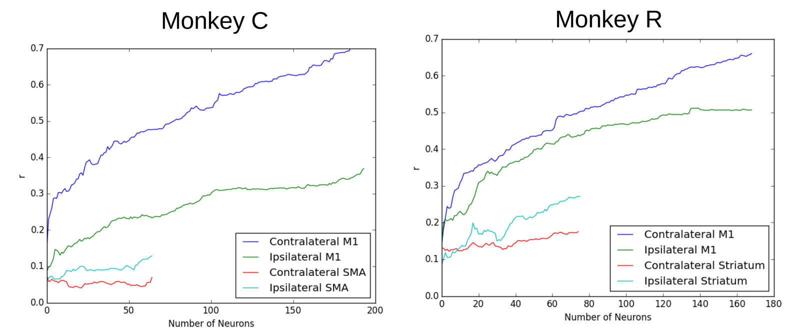
$$\text{Tuning Depth} = TD_i = \sqrt{a^2+b^2},\ TD_c = \sqrt{c^2+d^2}$$

$$\text{Preferred Direction} = PD_i = \arctan\frac{b}{a},\ PD_c = \arctan\frac{d}{c}$$

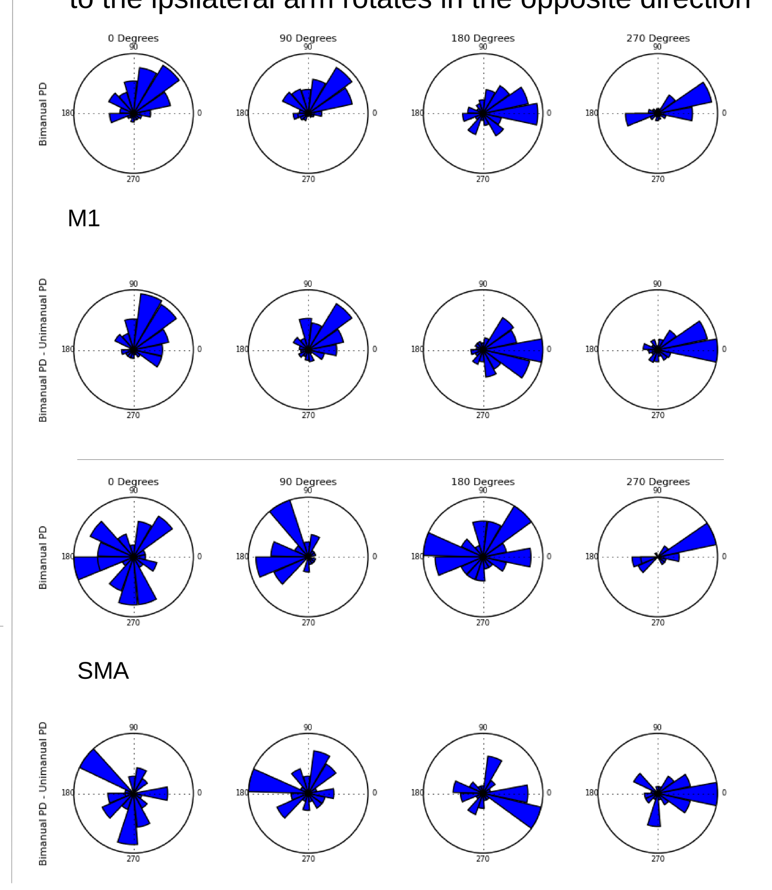
Tuning Model

Linear regression of binned firing rate and hand cursor kinematics

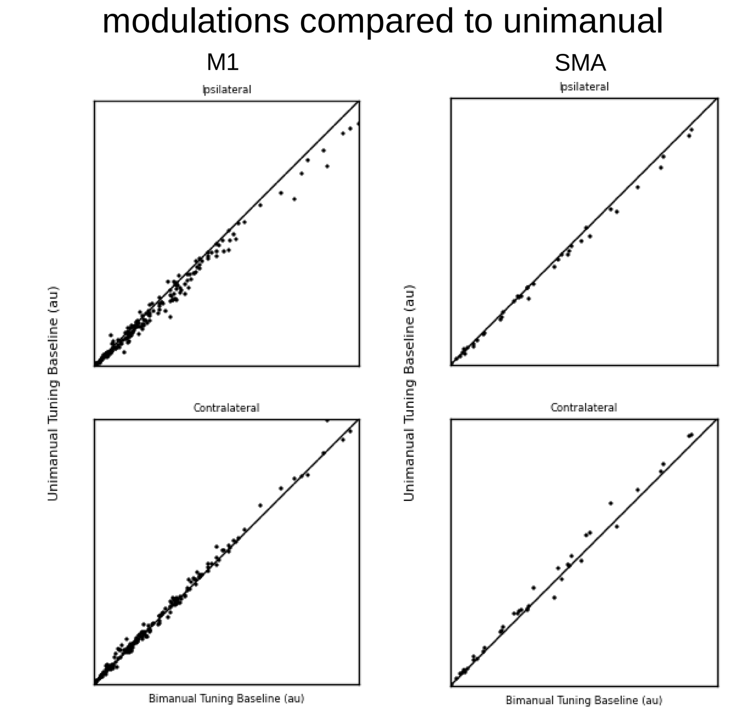
Ensembles can predict components of bimanual movements across brain regions



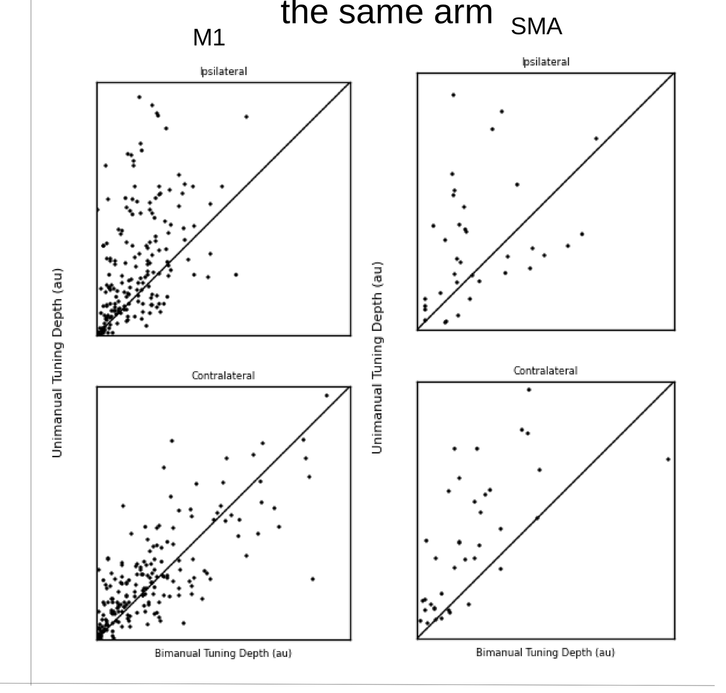
As the contralateral arm makes discrete movements from 0 to 270 degrees, the preferred direction of tuning to the ipsilateral arm rotates in the opposite direction



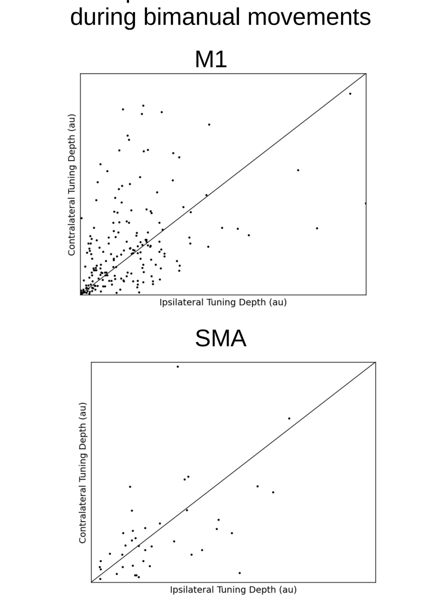
Bimanual movements cause increased neural modulations compared to unimanual



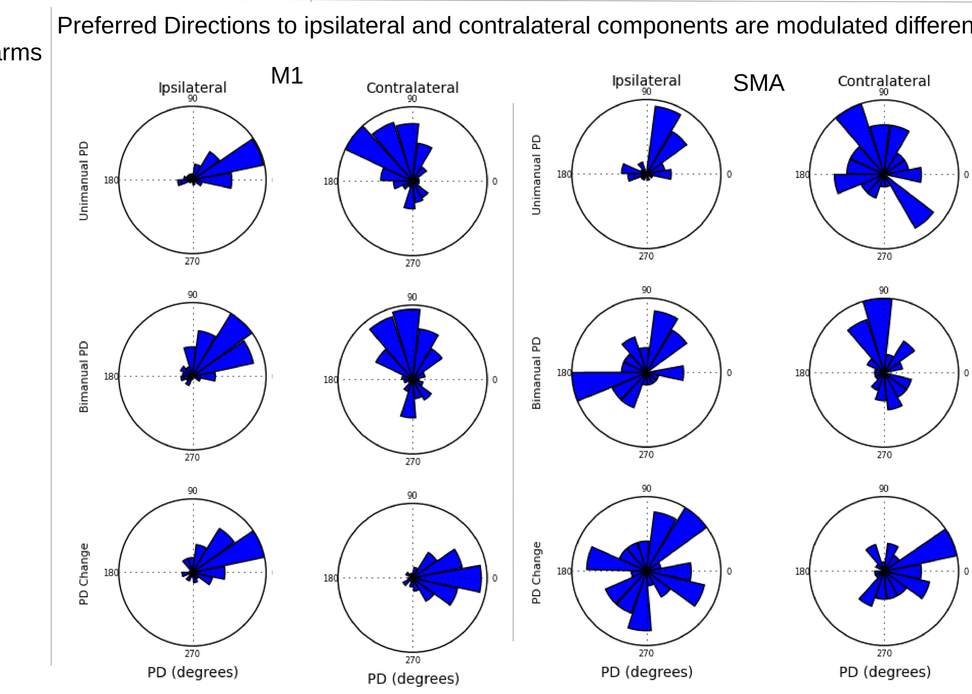
Tuning Depth changes between unimanual and bimanual movements of the same arm



M1 and SMA are correlated with both movement of ipsilateral and contralateral arms during bimanual movements



Preferred Directions to ipsilateral and contralateral components are modulated differently



Conclusions

- Ensembles of neurons in M1, SMA and striatum display different patterns of modulation during a bimanual joystick task depending on the pattern of movement
- Both contralateral and ipsilateral movements can be well predicted by M1 ensembles during bimanual movement
- Compared to unimanual movements, the sharpness and magnitude of the preferred direction can change during bimanual movements.
- In M1, the sharpness and magnitude of preferred direction appear to stay the same for the contralateral side, but change on the ipsilateral side. This change appears consistent across cells
- In SMA, the preferred directions exhibit greater changes during bimanual movements, with more changes on the ipsilateral side compared to contralateral
- Cells in both M1 and SMA exhibit relative location tuning during bimanual movements

Acknowledgements

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