intention or its saliency to ongoing motor actions. In contrast, motor cortical regions use sensory feedback to continue to perform a motor action or to select a new motor action.

2-E-57 Human force perception depends on arm posture

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The central nervous system receives sensory information about the state of the arm and interaction forces, which allows humans to efficiently interact with objects. Proprioception provides position information through the muscle spindles and force information through the Golgi Tendon Organs and tactile sensors. While the properties of position sense have been thoroughly investigated force sense received less attention. Previous research determined the discrimination thresholds for force magnitudes and force directions. However, the influence of arm posture or length of the muscles on the force perception is yet unknown. The goal of this study is to assess the accuracy of human force reproduction in different postures (arm orientations) in the horizontal plane. Subjects (n=12, all right-handed, 8 men) were restrained in a chair and held a handle attached to a force sensor while their arm was supported to prevent shoulder ab- or adduction. They were asked to perform a series of two interchanging trials: a reference trial, where they had to match an onscreen target force (10N) in magnitude and direction with visual feedback of the magnitude and direction of the exerted force, and subsequently a reproduction trial, where they had to reproduce the same force vector without visual feedback. In each of the four postures the subjects performed the eight force directions (45 degree increments) eight times (64 trial series per posture) in random order. The first hand position was located in front of the right shoulder with the elbow in 90 degree flexion (Posture 1: shoulder flexion (SF) I, elbow flexion (EF) I). By extending the elbow to 20 degrees flexion, the second position was obtained (Posture 2: SF I, EF II). For the third hand position the shoulder was extended from the posture at the first position such that the hand was on a straight line between the centre of the body and the second hand position (Posture 3: SF II, EF I). The fourth hand position was obtained by extending the elbow of the third posture to 20 degrees flexion (Posture 4: SF II, EF II). If the force perception depends on an egocentric reference frame, the results of the second and third posture should be the same because they are in line with respect to the centre of the body. For all arm postures, ellipses were fitted through the mean force reproductions per force direction for each subject and the joint contributions were calculated using the joint to endpoint Jacobian. The least accurate direction of the force reproduction ellipse was always pointing in the direction of the shoulder for all arm postures. The joint contributions showed that force sense is most accurate in the directions where both the shoulder and elbow contributed to the generated force direction at hand level. The results of this study demonstrate that force sense depends on arm posture, which cannot be explained by an egocentric reference frame.

2-E-58 Optogenetic perturbation and low-dimensional motor cortical activity

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Primary motor cortex (M1) and dorsal premotor cortex (PMd) play a prominent role in the initiation and execution of voluntary movements. Neurons in these areas generate dynamical patterns of activity which produce movement via downstream circuitry. However, our understanding of the relationship between the precise patterns of neural activity and behavior remains correlational. Causal perturbations in the motor system have been performed using methods that are too slow (e.g. pharmacology, lesions) or too imprecise (e.g. electrical stimulation, TMS) for the behavioral consequences to be causally linked to measurable perturbations of the neural population. Here we employ targeted optogenetic stimulation (AAV5-CaMKII-C1V1T/T, 3 mW, 561 nm) to perturb motor cortical activity during an instructed delay reaching task. In this task, reaction times (RTs) are faster when subjects prepare before moving. We reported previously that optogenetic stimulation of PMd disrupts preparatory activity and can partially erase the RT benefit achieved via planning, similar to electrical microstimulation (Churchland & Shenoy, 2007). Surprisingly however, unlike electrical stimulation, optogenetic stimulation in both PMd and M1 did not alter reach kinematics, even if delivered mid-movement. The magnitude of neural firing rate changes induced by stimulation were massive relative to the patterns of activity observed during non-stimulated trials (6.4-13.2x variance). Following stimulation, isolated neurons displayed firing rates increased by 25-200 Hz out to 2 mm laterally from the light source. We asked whether this contrast between strong neural perturbation and weak behavioral consequences results from a misalignment between the optogenetic perturbation and the patterns of neural activity relevant to the behavioral task. We applied PCA to non-stimulated firing rates to find a low-dimensional subspace explored by task-activity and therefore likely to encompass dimensions of behavioral relevance. We found that the majority (83.1-91.6%) of stimulation-induced changes in firing rates projected orthogonally to this low-dimensional subspace. This provides direct evidence that some unexplored directions of neural activity are indeed irrelevant to task performance. Furthermore, we used demixing PCA to segregate dimensions of neural activity for which modulation is similar across all reach directions, versus modulation which diverges across directions, which are more likely involved in specifying movement specific activation patterns to downstream readout circuitry. We found that only 4.4-6.2% of overall stimulation projects onto reach direction-dependent modes of task-related activity, which likely mitigates the behavioral impact. These results suggest that better aligning the vector of optogenetic perturbation with behaviorally-relevant axes of neural activity could enhance behavioral modulation and more informatively probe the relationship between neural activity and behavior.

2-E-59 Small force cues can communicate motor goals and distinguish skill level during human-human sensorimotor interaction.

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Sensorimotor interactions between two people working towards a common motor goal such as moving a table together are part of daily life, yet we know little about the sensorimotor control that governs such interactions. Understanding how sensorimotor interactions promote motor skill learning and provide motor assistance is important for understanding the role of therapists and robots in rehabilitation. As a first step, we studied the nature of force interactions between human partners during a cooperative motor task. We chose partnered stepping as our experimental paradigm because: 1) force cues are the primary mode of communication, allowing the task to be performed in the absence of vision, 2) there are explicit motor goals that can be used to evaluate performance, and 3) differences in interactions based on motor expertise can be studied by comparing experts and novices. We sought to identify the magnitude and sign of force cues between individuals during partnered stepping, determine if force cues contain information about movement goals, and evaluate how force cues change with practice and motor expertise. Expert partner dancers (n=8) with a minimum of 10 years experience and novices (n=24) were recruited and tested in Novice-Novice (NN) or expert led Expert-Novice (EN) dyads. Participants were blindfolded and held end-effectors with 6-