Neurons in Action

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Much of brain research is fueled by the wish to unravel the foundations of thought and action (1). Whereas the complex neural processes that underlie consciousness are beginning to be elucidated, the simpler neural circuitry that drives perception and the generation of movement surprisingly remains unclear. For instance, we still do not know whether movement depends on a few localized neuronal circuits or the dynamic state of multiple distributed neuronal systems. Much of the hope surrounding neurorobotic devices that translate the activity of neurons in the brain into muscle movements depends on understanding how neurons normally initiate and control skeletal muscles. Toward this goal, work by Taylor et al. (2) on page 1829 of this issue reveals that the activity of a small group of motor cortex neurons in monkeys can be fine-tuned to carry out complex three-dimensional (3D) movements.

Much of our knowledge about neurons has come from studies of the neuromuscular junction, the point where nerve and muscle meet (3, 4). When parts of the motor system are damaged through injury or disease, repair efforts concentrate on trying to restore the link between neuronal activity and muscle contraction. There have been attempts to achieve this using noninvasive methods, such as electroencephalography (5). In this case, recording of the bulk signal of millions of neurons in the motor cortex is analyzed online, resulting in information rates of up to 1 bit/second that can be harnessed to control real-world devices that, for example, dial the phone or switch on the heating.

However, in order to restore speed and fluidity to the motor system, the activity of more neurons needs to be commandeered. The question of exactly how many neurons is crucial for understanding cortical representations of movement in the brain. Experiments using single-neuron electrode recordings in monkeys as they perform a reaching task suggest that movement depends on activation of millions of neurons in a wide area of the motor cortex (6). Each neuron in the motor cortex is maximally active for a particular direction of movement, but also fires to a lesser degree in response to movements in other directions. The average of the preferred move-

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ment direction weighted by the activity of neurons then accurately predicts the actual movement performed. This explains many properties of the motor cortex, but also raises several questions. How is the sensory system, with its emphasis on specificity of representation, coupled to the distributed representations of the motor system? How many motor cortex neurons need to be recorded simultaneously in order for real-time movements to be controlled (7)?

Taylor et al. (2) begin to shed light on some of these puzzles. They recorded neuronal activity in the motor cortex of monkeys as the animals made real and virtual arm movements in a computer-generated 3D virtual environment. The monkeys moved a cursor from a central start position to one of eight targets located at the corners of an imaginary cube (see the figure). Their hand movements were represented by two spheres: one being the stationary “target,” and the other a mobile “cursor” whose motion was controlled either by the monkey’s hand (hand control) or by recorded activity of cortical neurons (brain control). Taylor and colleagues investigated the effects of visual feedback on the monkey’s hand movements generated by cortical signals in a closed-loop system.

Intriguingly, the notion of a widely distributed population code is the foundation on which Taylor et al. built their study. Yet, their results seem to suggest that effective encoding of motor actions can be accomplished with a very small number of neurons. There are several explanations for this paradox. The first is that learning is crucial. The properties of the recorded cortical neurons became adapted over the course of days, allowing more and more precise control of the cursor. Second, the monkeys relied on visual feedback to fine-tune the properties of the small group of recorded neurons, demonstrating that the visual and motor systems are tightly coupled rather than separate modules. The two new elements in the Taylor et al. study—namely, the closed-loop system and visual feedback—are likely to have practical consequences for the design of neuroprosthetic devices. It now seems that only a few recorded neurons, or local groups of neurons, become adapted to actually control movement.

Independently, Brecht and colleagues have shown that injecting a current into a single neuron in the rat cortex elicits a short sequence of action potentials that lead to detectable whisker movements (8). Thus, the cortical representations of the motor system may not be that global after all. This is reassuring given the similarities in the anatomical organization of sensory and motor cortical structures. The functional properties of different cortical areas, like their anatomical organization, may turn out to be variations on a common theme.

References