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Summary:

Somatosensory feedback from the limbs plays an essential role when we learn to make new movements. A recent study shows that motor learning can be accomplished purely through observation, and motor learning by observing also critically depends on the brain's somatosensory system.

Text:

Flip through any neuroscience textbook and you'll find colorful maps of the brain neatly dividing the cortical surface into functions. In most cases, blobs of cortical tissue thought to be involved in perception rarely if ever overlap with blobs involved in motor control. The impression these pictures give is that perception and action invoke neural operations that are entirely separable. However, recent work in cognitive neuroscience has blurred the textbook lines between representations of sensory and motor processes in the brain. A new paper by McGregor and colleagues provides further evidence for a sophisticated *sensorimotor* system for motor learning via observation of others' motor learning [1]. Although initially driven by vision, this system seems to rely on somatosensory areas in the brain—areas essential for actually performing motor learning.

Interest in the neural overlap between perception and action has grown, in part, from the early-90s discovery of neurons that have both perceptual and motor properties. Mirror neurons, first noted in the premotor cortex of macaque monkeys, fire during both movement execution and the observation of similar movements [2]. Since their discovery, functional neuroimaging work in humans has demonstrated that action observation activates an extensive network of perceptual and motor areas well beyond the occipital lobe's visual centers [3, 4, see Figure]. Supporting this work, behavioural studies have causally linked the brain's motor areas to perception [5, 6], and perceptual learning has been shown to drive improvements in motor learning and neural changes in the brain's motor systems [7]. While many have hypothesized that the sensorimotor systems revealed by these and related tasks might play a role in high-level behaviors such as empathy and language [8, 9], a quieter line of research has explored their impact on how we come to make accurate movements.

Motor learning is typically studied in the lab by having participants grasp the handle of a robotic arm and make timed reaching movements. To induce motor learning, the robot is programed to apply a few Newtons of force to the hand. Typically, the force is applied perpendicular to the direction of movement and proportional to movement velocity causing straight-line movements to curve [10]. Such force fields, as they are called, are similar to the

rotational forces we frequently encounter during a quick turn to pick something up—forces we learn to overcome during development. Indeed, with a small amount of practice, participants learn to skillfully counter robot-induced force fields so that reaches become nearly indistinguishable from previously made unperturbed movements [10].

Over the last decade, several studies have demonstrated that this type of motor learning can occur purely through the observation of someone else—a “tutor”—learning to move a robotic arm in a force field [11, 12, 13]. Dubbed “motor learning by observing”, the phenomenon doesn’t rely on cognitive strategies. Solving math problems during the observation of motor learning, for instance, has little impact on the benefits of observation [11]. With cognitive strategies ruled out, it remained unclear how visual signals representing the tutor’s motor learning could alter motor circuits in the observer’s brain. One possibility was that these signals might be applied to relevant motor circuits via the somatosensory system. In a new study, McGregor and colleagues use behavioural testing and neural interference to provide evidence for this idea [1].

In their experiments, participants first watched a video of someone learning to compensate for a force field that pushed the arm to the left during reaching movements. They then actually experienced and had to adapt to a force field that pushed their own arm to the right during reaching movements—that is, they performed the *opposite* motor learning task to that observed in the video. The idea, here, was that watching the video would drive motor learning of the leftward force field, and this motor learning by observing would be revealed as interference (a greater increase in movement error) when participants had to then learn to move in the opposite force field.

To test the role of the somatosensory system in motor learning by observing, some participants had their median nerve stimulated by a small electrical current during observation of the leftward force field. The median nerve is a well-documented source of sensory input from the arm [14]. If the somatosensory system is involved in mapping visual signals of a tutor’s motor learning onto motor circuits in the observer’s brain as the authors’ hypothesized, perturbing it via median nerve stimulation should interfere with motor learning by observing.

In a replication of previous work, observation of someone learning a leftward force field caused increased movement error when participants initially experienced the opposite force field [12]. This increase in error showed that participants had learned something about the dynamics of the leftward force field purely through observation, and their motor system expected these dynamics to apply when they moved the robot themselves. However, in a new twist, when the observation of motor learning was paired with median nerve stimulation the increase in error completely disappeared. That is, the addition of a somatosensory system perturbation during the observation of force-field learning abolished the motor system’s learning of the force field in the video. Thus, when participants made movements in the opposite force field there was no increase in error compared to those who weren’t stimulated.

The result implicated the somatosensory system in motor learning by observing with one caveat: stimulation may have simply diverted participants’ attention away from the videos. To rule this out, a control study demonstrated that applying stimulation to the arm opposite to the one observed in the videos fully restored motor learning by observing. And, in a final experiment, electroencephalography (EEG) was employed to record neural responses from primary somatosensory cortex; the responses were evoked via median nerve stimulation and recorded before and after participants observed motor learning. Observing motor learning

changed the size of the evoked neural response from S1, and these neural changes correlated positively with the amount of motor learning by observing.

The experiments provide an initial demonstration that the somatosensory system is involved in motor learning by observing. The work also supports (but does not prove) the authors' hypothesis that the somatosensory system could enable motor learning through observation by linking visual signals of a tutor's learning with motor circuits in an observer's brain. More generally, the results add to a growing body of literature suggesting that action observation activates many of the same neural systems used for action execution [3, 4, 15] and, most significantly, this neural activity is behaviorally relevant [7, 12, 16].

When we experience new environmental forces, such as a strong wind, or the annoyance of recently installed braces, our movements are initially perturbed; we stumble as we walk down the street or slur our words during speech. But, with a little practice, we learn to once again move accurately. The brain learns to counter disturbances such as these by updating its model of the environment to produce motor commands that account for the newly imposed force [10]. Across motor behaviors, this type of motor learning can place a primary reliance on the somatosensory system [17]. During speech, for instance, the brain compares predicted somatosensory signals from the articulators with those actually perceived. If speech movements are perturbed, the motor commands that drive speech movements are updated until errors between predicted and perceived somatosensory signals are minimized [18]. Such motor learning occurs even if the perturbation does not alter speech sounds.

If motor learning through pure observation also relies heavily on the somatosensory system, as this new study demonstrates, it provides key evidence that the phenomenon acts through neural systems associated with *actually* performing motor learning. Of course, this conclusion leaves a lingering question: why doesn't every tennis fan hit forehands like Roger Federer? For one reason, the benefits of motor learning by observing depend on watching someone go through the trial and error process of learning to make new movements. Observing someone failing to learn—such as someone who is already an expert (e.g. Mr. Federer)—provides no benefit to observers when they actually go to learn the task. Learning to make movements through observation requires the perception of a learnable error signal, just as it would for active motor learning [1, 11, 12, 13]. When it comes to the distinction between action and action observation, the brain might see less of a difference between these behaviours than your average neuroscience textbook would have you believe.

Figure Legend:

The coloured parts of the image show brain areas activated by observing right arm reaching movements and right arm motor learning similar to that which occurred in the reviewed study [1]. RIGHT refers to the right hemisphere, and LEFT refers to the left hemisphere. The image demonstrates that action observation activates brain areas beyond visual centres in the occipital lobe. Many of the same neural systems used for action execution are active during action observation, including motor areas in the frontal lobe (anterior to the central sulcus) and somatosensory areas in the parietal lobe (posterior to the central sulcus). The figure was adapted with permission from Figure 2 in reference 4.

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