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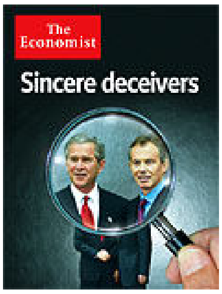

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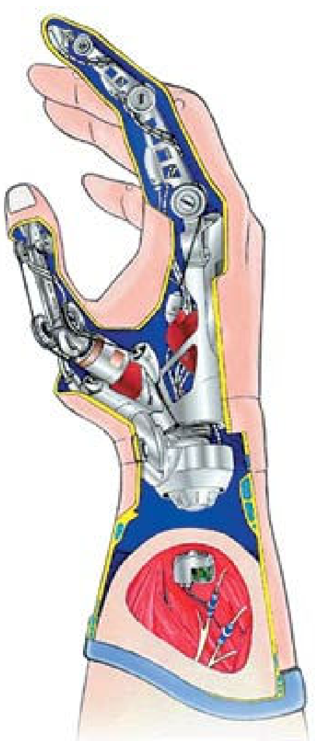

Sensory feedback: Adding the sense of touch to artificial limbs could improve dexterity and make them feel more like part of the user's body

ARTIFICIAL limbs have come a long way since the humble hook and peg. Today's most advanced prosthetic forearms, for example, enable amputees to grasp and release objects at will by selectively flexing muscles in the remaining arm. But there is more to picking up and putting down objects than simply being able to open and close one's fingers. An egg needs to be handled differently from a heavy glass tumbler. What is missing from today's prosthetics is sensory feedback—in other words, the sense of touch.

Such feedback would not only help to improve dexterity and control, says Ken Horch, a bioengineer at the University of Utah, but might also make prosthetics feel much more like part of the body, rather than an appendage or extension to it, by closing the feedback loop between the device and the brain. But while much work has already been done to show how motor-neuron signals from the brain's motor cortex can be translated into control signals for motors, there has so far been little research into sensory feedback. Some scientists, however, are now beginning to close the loop.

In the past few months a dozen amputees were given the first glimpse of what it might be like to have a truly bionic arm. A group led by Dr Horch connected electrodes to peripheral nerves in the subjects' forearms to both record and stimulate neural signals to and from a robotic arm. Although the arm was not attached to the subjects, they were able to control it as though it were. Readings from force sensors in the gripper were translated into nerve impulses

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equivalent to pressure, enabling the patients to "feel" natural sensations as though through the device's fingers. This made it possible for them to gauge how much pressure to apply when commanding the motors to grip. In addition, position sensors in the robot's joints were translated into "proprioception" signals that enabled the subjects to feel the arm's position, even when their eyes were closed.

What makes this kind of thing possible is that, remarkably, scientists have succeeded in decoding a lot of the neural signalling needed to create artificial sensations such as pressure and proprioception. Human skin is, for example, capable of sensing four different types of tactile sensation: contact, vibration, sustained pressure and skin stretch.

The real challenge now lies in developing ways to communicate with individual nerve fibres on a one-to-one basis, says Paolo Dario of the Scuola Superiore Sant'Anna in Pisa, Italy, who is heading an ambitious project called Cyberhand. Funded by the European Union to the tune of *euro*1.5 million ($1.8 million), it combines the results from research groups in four countries. The aim of the project is to develop a prosthetic hand controlled by a neural interface, capable of independent finger movement and sensory feedback.

Another researcher involved in the Cyberhand project, Ronald Riso of the Centre of Sensory-Motor Interaction at Aalborg University in Denmark, says the difficulty lies in developing electrodes small enough to communicate with single nerve fibres without moving. Without a near one-to-one mapping of electrodes to nerve fibres, the wrong kind of nerves could receive the wrong kind of stimulation, producing an unpleasant pins-and-needles sensation.

Dr Horch's electrodes achieve this one-to-one mapping but have to be temporarily implanted; after his tests they were pulled out. The Cyberhand team's solution is to try to encourage nerves to grow through "sieve electrodes" which, as their name implies, have lots of tiny holes in them. These problems, and the difficulties of getting approval for permanent implants, mean that sensation that is rich enough to convey the feeling of different textures is still a long way off. But for most amputees, being able to grip an object without dropping or crushing it would make a big difference.

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Dr Ken Horch publishes his research on neuroprosthetics. See also the Cyberhand Project.