Unlocking communication with the nose

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It is the start of your day. As you shower and mull over all of the things you hope to accomplish, you pass out without warning. You awaken days later, in the hospital, on a ventilator, unable to move your arms or legs, unable to cry out. Worse yet, the nurses and doctors passing by do not seem to realize that you are wide awake. They talk about your coma, your physical needs, and your brain scan showing a brainstem stroke, oblivious that you can hear all that they are saying. Finally, one of them notices your eyes, moving ever so slightly, upward or downward. They instruct you to move them up if you can hear them. You comply. So begins a long, slow process of recovery as both you and the medical team realize you are "locked in." Although communicating through eye movements is feasible, it is difficult, and you are desperate to find an easier means of expressing yourself. It turns out that an effective solution is right under your nose. In PNAS, Plotkin et al. (1) demonstrate the efficacy of sniffing as an interface for communication.

What is Locked-in Syndrome?

First described in 1966, the locked-in syndrome is distinctive for preserved consciousness and an inability to move the limbs, face, or vocal apparatus (2). It is classically associated with injury to the ventral pons, effectively cutting off the corticospinal and some of the corticobulbar motor pathways. This lesion location will spare the oculomotor nucleus in the midbrain and allow the patient to make volitional vertical gaze eye movements. In many cases this is the only direct means of communication. There are many possible causes for a lesion in the brainstem, including sudden hemorrhage from high blood pressure, as in the example above (3). Before the original description in 1966, the diagnosis was likely unrecognized, and outcomes were uniformly fatal owing to lack of ventilation and infectious complications, particularly pneumonia. Even today, ≈75% of quadraparetic patients will develop pneumonia or segmental collapse of a lung within the first month of hospitalization (4). By the 1980s, at least 40% of patients were surviving, mainly because of advances in pulmonary medicine and the aggressive care by dedicated respiratory therapists (5). Survival continues to improve, with recent studies suggesting 85% survival in those who make it through the first months of care (6, 7).

With the advent of better methods of communication, it is clear that, despite a high incidence of depression, most locked-in patients want antibiotics, want aggressive medical care, avoid "no-code" advanced directives, do not seek euthanasia, and want to stay alive (7). Some can return home provided there is sufficient support for their care. Although communication is slow, any effective method to accelerate the rate of information transfer between patients, families, and caregivers is of enormous value. This need is not limited to locked-in patients. There are many additional patients with quadraparesis and anarthria of other causes, including spinal cord trauma and advanced ALS, who would benefit from assisted communication. In parallel, there is a growing demand for providing patient-controlled motorized wheelchairs to enhance their mobility.

Plotkin et al. demonstrate the efficacy of sniffing as an interface for communication.

Enabling Technologies in Quadraparesis

Recognizing this need for better communication and mobility devices, we are now in the midst of an explosion of creative engineering. Enabling technologies for improving the quality of life for quadraparetic patients are steadily emerging. There are already a number of commercially available devices that track eye position so that patients can select letters on an alphabet board. However, these systems are expensive, and many patients do not like using them because they require enormous concentration and are fatiguing. The requirements of eye-gaze communication are just too difficult for many to master. One alternative technical solution transforms brain activity rather than eye movements into useful instructions. The feasibility of creating a brain–computer interface (BCI) was demonstrated more than 20 y ago with EEG scalp recordings of electrical potentials (8). There are now many EEG-based approaches under development (9). In most of these applications, a specific evoked brain response, such as the "p300," can be manipulated by subjects while they process visual or auditory information that is expected or unexpected (10). The p300 and related BCI methods are usually learned rapidly. When integrated with a digital alphabet board, they can be used to spell out words. They have also been used to start and stop a wheelchair that is constrained to a predefined pathway (11). Major efforts are under way to expand the operator responses to more than just binary choices and to export more of the task processing to the computer, whether it is word recognition or robotic control to the device (12).

Another noninvasive approach with the potential for "mind reading" is functional MRI (fMRI) (13). Although it is unlikely that the cost and constraining environment of an MRI scanner would ever lead to its routine use as a communication device for patients, experimental work in fMRI mind reading has pushed the BCI field as a whole because of the development of multivoxel pattern classification for decoding brain images. These are sophisticated machine learning algorithms that can be trained to recognize brain signatures that identify at least some aspects of a person's mental state (14). Both EEG and fMRI methods suffer from very low information transfer rates, motivating the search for other engineering solutions.

Invasive BCI is another fascinating approach that is already under clinical evaluation at a limited number of research centers. It involves placement of a multielectrode recording system directly into a patient's brain (15). The recorded signals can be used to move cursors on a screen, select button presses, operate a robotic arm, and form computer-generated syllables (16). Wireless systems are now capable of transmitting useful signals without the patient being tethered by wires from their brain to an external amplifier. Efforts are under way to understand where best to place electrodes in the brain, how to efficiently decode neural activity, and what to train patients to do. Clearly, these invasive solutions have technical strengths. The most important is a faster information transfer rate than what is available with the noninvasive solutions. This potential advantage is offset by significant costs and the risk of brain surgery. It is too soon to know how

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this field will evolve, but it is likely that both noninvasive and invasive commercial solutions will emerge over a long time horizon.

Communication with Preserved Musculature

In the immediate future, the most practical engineering solution is to find skeletal muscles with preserved voluntary activity and record and amplify their responses (17). As they recover, locked-in patients will regain control of muscles in their face, tongue, or even a limb. Teams of engineers and rehabilitation physicians routinely build devices that can sense small isolated movement to generate a signal that can be used to interact with alphabet boards or wheelchair controllers. In this context, the solution by Plotkin et al. (1) is most relevant. Their device links an ordinary nasal cannula, the ubiquitous tube used to blow oxygen into a patient's nose, with a pressure transducer and computer interface. The device is sensitive to differences of air pressure through the nose. That is, it senses whether a person is sniffing. Sniffing is controlled by opening and closing the soft palate. The brainstem innervation of this musculature can be spared in locked-in patients and is also preserved in ALS and patients with high cervical quadraparesis. The investigators demonstrate that normal volunteers can rapidly learn to use sniffing to control a binary response. Sniffing is fast, with speed and accuracy comparable to a mouse click or trigger response on a gaming joystick by the index finger. The volunteers quickly learned to use a communication device and could even drive a wheelchair in an open path via a simple sniff "Morse code." More importantly, in clinical testing, the authors tested their device with three locked-in patients and one patient with quadraparesis and anarthria.

The nasal transducer is relatively cheap, built on available technology, readily learned, of low risk, and useful. It can profoundly impact a patient's quality of life. Patients in the clinical trial were able to have meaningful interactions with their families, in one case after years of silence. One patient was also able to navigate a wheelchair through a difficult obstacle course.

Like all devices, the utility of the nasal transducer will have boundary conditions to be discovered and surpassed with future improvements. The information transfer rate remains slow, in part because of the patient's cognitive state or ability and in part because of technical limitations of the alphabet board used in the study. Computer-based alphabet boards that use word completion algorithms like those found in smart phones could greatly accelerate communication speeds. Another major issue is whether a nasal communication device will work in the ventilated patient. The authors show that with some minor modifications their system will work in a patient who has a tracheostomy. An important next step will be to determine whether patients with advanced ALS who require mechanical ventilation could also use the system. It also remains to be determined when the nasal transducer would be a better solution than a sensor linked to some other functioning muscle. As these questions are worked out, the good news is that the authors have translated their expertise in sniffing, an often overlooked but ubiquitous human behavior, into a dramatically useful clinical application.

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