paratus employs wide-bandwidth electrostatic transducers, which minimize distortion. Pompei recently demonstrated this device by beaming a John Coltrane saxophone solo around the room. "You'd probably notice that it's not as good as a loudspeaker," he admits. Still, he says, he is able to project a three-degree-wide beam for some 200 meters.

Norris and American Technology Corporation have also been pursuing the prospect of using parametric arrays in air. Norris's system, like Pompei's, has had difficulty with distortion, particularly at low frequencies. But Norris claims that custom piezoelectric transducers that he and his colleagues have started using in the past few weeks have sufficient bandwidth to have "licked" the problem: "All of a sudden now we can play music." So the competition between his company and the Media Lab for beaming sax players around large rooms is sure to heat up. *—David Schneider*

FIELD NOTES

PHANTOM TOUCH

Imbuing a prosthesis with manual dexterity

"Whee!" exclaims Melissa Del Pozzo, a vivacious 10-year-old who is watching an electrical trace on a computer screen undulate up and down like ocean swells. Born without a left hand and lower forearm, Melissa makes the signal oscillate by moving either a tendon or muscle in the arm that would have been used to flex her thumb. A sensor attached to the skin just below the elbow detects the slight movement and relays it to a window on the screen.

"Whee!" Melissa repeats. This time a line wiggles in another window. This one corresponds to the tendon or muscle that initiates pinkie motion. Melissa's ability to trigger separate waves marks the promise of a new technology that may allow her to achieve her dream of playing piano with both hands. The electric signals represented by the fluctuating lines can be used to move independent fingers in what may be the first dexterous prosthesis.

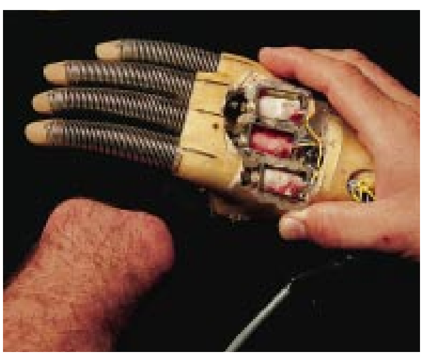
Melissa found out about the testing taking place at Rutgers University's department of biomedical engineering in Piscataway, N.J., just this past June. Her

NAJLAH FEANNY SABA

CONTROLLING ELECTRIC SIGNALS BY TENDON AND MUSCLE is Melissa Del Pozzo* (right), *who might one day similarly control a prosthetic limb.

parents showed her an article in the *Asbury Park Press* about Keith St. John, a 35-year-old amputee who was testing a hand with three-fingered movement. That was a definite improvement over her own state-of-the-art hand, which consists of a claw covered with plastic that can execute only a simple open-and-shut grabbing motion when activated by an electric potential from muscles in the forearm. After reading the article, Melissa implored her parents to make a call to the researchers, William Craelius, an associate professor of biomedical engineering, and his doctoral student Rochel Lieber Abboudi.

Some half a dozen amputees had made the mechanical fingers wiggle or the lines on the screen oscillate. Melissa so far is the only one to have been born without a hand who could manipulate the signals; two others missing hands from birth could not make the lines jump. Melissa, like some other subjects, reports that she can feel control over missing hands and fingers—a phenomenon known as phantom limbs.



NAJLAH FEANNY SABA

PROSTHETIC HAND allows flexing of single fingers when actuated by tendons or muscles.

Her visits to Rutgers are a prelude to fitting her with a hand and the requisite control apparatus. Researchers will fashion a silicon sleeve equipped inside with pressure sensors. On top of the sleeve will sit a hard plastic socket that serves as an exoskeleton on which to anchor the hand. The hand itself is a commercial wooden product used on other prostheses. It is fitted with electromagnets that move each of three fingers separately. When a tendon moves, it causes the sensor—a small diaphragm filled with air—to emit a puff that travels through a tube to a transducer that senses the pressure and transmits an electric signal to the artificial hand. Craelius decided to focus on a tendon-actuated system because of the difficulty in isolating specific muscle groups that can move individual fingers. In the case of Melissa and others missing a lower forearm, where tendons are most accessible, muscles from the upper arm can sometimes be utilized.

The tapping motion that Craelius and his colleagues have demonstrated may suffice to play the piano or saxophone, type on a keyboard or let a court reporter work a stenotype machine. One subject, Jay Schiller, played "Mary Had a Little Lamb" at one-quarter speed. He made only two mistakes, one with his still intact hand. The entire project, though, demonstrates the difficulties inherent in designing the bionic human. Activating a tendon or muscle for each finger may eventually enable Melissa to play the piano, but it will remain a daunting challenge to achieve the full 24 degrees of freedom—that is, the 24 distinct movements—that the human hand can produce.

Triggering finger movement by retraction and extension of a tendon is what engineers call biomimesis, a replication of the body's own control mechanisms. But the tendon's simple back-and-forth motion will not suffice to reproduce a full range of motion. If it ever becomes possible to flash the "V" sign with a prosthetic hand, it will require some novel stratagem. More sophisticated sensors and control programs might anticipate and act on the prosthetic user's demands. Alternatively, the user might initiate different finger movements by flexing sensor-fitted toes.

Going beyond mere taps will require additional engineering. If the signal is held constant for a long time, the hand's electromagnets burn out. "What if you want to hold a cup of coffee for more than a few seconds? That's pounds of pressure and amperes of current," Craelius points out. The Rutgers team is interested in a hand that contains more than one magnet to manipulate each finger. An electromagnet could move a finger, and an accompanying permanent magnet could hold it in place.

The mechanical hand may prove unnecessary for some tasks. In fact, Craelius, Abboudi and their co-workers received a patent not for the prosthetic appendage but for the method of tendon-based control. The importance of the control system is underlined by an upcoming project. The prosthesis—replete with controller and mechanical hand—may serve as a backup for the first hand-transplant operation, which is scheduled to take place at the University of Louisville in Kentucky before year's end. If the patient's immune system rejects the hand, the Rutgers prosthesis could serve as either a permanent replacement or a device that would permit the tendons to be exercised until another transplant can be found. But Craelius emphasizes that the hand is not essential. The Louisville transplant patient, a computer programmer, could attach the tendon sensors directly to the computer for writing software. As such, the Rutgers project may revise the very definition of manual control.

—Gary Stix in Piscataway, N.J.

