Editorial

TIGHTENING THE LOOPS ON SENSORY FEEDBACK

Ma Bell's radio and TV ad theme, "reach out and touch someone", appeals to everyone. It represents contact with those sensitive, often sentimental, emotional connections we have with our environment and the people and things that we value. In real life, it is only one's voice and the feedback of the voices of our familiar compadres that makes situations comparable to the telephone company ad warm and real. We all know the experience. What makes it work?

Many years of experience in the serious pursuit of possible answers to this question, and its broader implications concerning the role of sensory feedback in shaping human performance, have brought us only a few answers on which we can count. Mostly, we only know that the importance of sensory feedback varies greatly with specific situations, and that the role of the senses is very complex because of two-way filter interactions with the central nervous system. We do know quite a lot about the specifics of the sensory receptors themselves. It is, however, the manner in which the patterns of sensory stimuli provide information for processing by the spinal cord and higher levels that is clinically provocative.

With specific reference to limb amputees, everyone agrees that to achieve functional unity with a prosthesis, there must be some form of awareness established by the wearer about the capabilities of the prosthesis. How reliably does it respond to the amputee's command? Does it react predictably to each familiar environmental situation so that the wearer has an accurate mental model of what to expect? Getting a wrong number does not reach out and touch the expected connection. After too many wrong numbers or too much noise in the connection, one tends to lose that warm feeling of predictable expectation. This appears to be the case in the matter of the state-of-the-art with sensory feedback in limb prosthetics.

We have long known that the primary source of sensory feedback for limb prosthesis wearers was an "open loop" mental model of the space occupied by the prosthesis, its dynamic control features and pressure patterns on the stump—all modulated by visual, and sometimes auditory, information from both the prosthesis and its situational environment.

To date, except for blind amputees where any feedback from the environment is helpful, we have not been able to definitively establish whether or not specialized sensors located on the prosthesis itself could effectively communicate signals to the wearer that would significantly enhance task performance. Experimental results have, for the most part, been marginal and frustrating, both scientifically and clinically.

Despite many disappointments, especially in terms of immediately useable clinical benefits, our knowledge base has been substantially broadened, mostly concerning the scope and complexity of factors that realistically must be brought under control. For example, in the biological model of a limb, it is known that receptor density for cutaneous and kinesthetic senses (pressure, pain, thermal, etc.) may reach several hundred per square millimeter. These high receptor densities provide precise patterns of environmental information. They generate functionally important physiological and psychological adjustments of information flow rates. Refined movement may require highly defined sensory patterns to optimize the available muscle capability of the normal limb. The stability and continuity of these patterns is identified with the integrative function of the central nervous system. The distortion of the patterns by modification from disease, or by total physical destruction, requires laying down new cognitive adaptations. These adaptations can only reach a degree of approximation to the original system. The extent of the sensory side of the approximation is dependent on the capability for sensory input that remains or is replaced. Substitution of one pattern of signals for another depends on achieving a common coding scheme. Whatever scheme is achieved, it must be compatible at both the input and output sides of the person-prosthesis loop. Missing or distorted patterns are functionally reconstructed into new channels, both by means of the "software" of the brain, and substitution of sensors. When the sensations are natural, e.g., from the surface of a stump, the sensors available probably were not previously used for primary information about the location of and forces on the limb in space. New cognitive patterns must be brought into association. These new patterns may only provide part of the information previously presented, or the information provided may not be relevant. Thus, there may be a permanent substantial loss of skill.

The original, natural, learning process in the intact person seems to make use of whatever sensory function is available to provide a pliable, plastic motor output capability. This is subject to refinement of precision according to criteria set genetically (e.g., walking), or learned according to environmental and personal, i.e., cognitive set standards for performance. "Normal" gait for a leg prosthesis wearer, "smooth," "coordinated" delivery of a fork full of food by an arm amputee, may have to come to mean something different, cognitively, than these actions for the non-amputee.

For the amputee, complex situational vectors are set up by a combination of motor deficits and sensory deficits. This makes it especially difficult to independently assess the role of sensory feedback in task performance. For example, direct observations of the role of the senses is confounded by factors such as the transmission precision of the power train, by dynamic stability properties of the structural interface between the stump and the socket, and by task complexity, e.g., climbing stairs, rotating a door knob, etc. A simple analog would be to try to observe the role of sensory feedback in the performance of a non-amputee who was trying to write with a pencil that had the tip attached to a soft, compliant, rubber-like shaft. The capricious relationship between the tip of the pencil and the writer would make interpretation of the performance associate more closely with the hardware interface between the writer and his task than with the properties of the writer's sensory-motor system.

To function with maximum effectiveness, the communications channels, as well as the energy (power) transfer channels, must be locked intimately and reliably together in both the relationship of time, e.g., minimum transmission time-lag, and geometric positions. It seems probable that sensory information, to be effective, must have a tight, reliable, one-to-one superposition with a tight, reliable motor output system.

It is, thus, our view that perhaps a major reason for not being able to obtain clear-cut experimental results with artificial sensory feedback techniques for limb prostheses is that the linkages between the subsystem interfaces have usually been excessively "loose." The messages in both directions are garbled. As the requirement for task precision increases, the effects of loose communication links become increasingly evident. Softness of fit between the prosthesis and the flesh of the stump, for example, generates uncertain messages in both directions. The "reach out and touch" is a spongy approximation, a sensory haze at the cognitive level.

The bad news is that in the prevailing situation, where direct bone attachments have not reached a level of development suitable for standard clinical practice, the tightening of sensory feedback loops and feed-forward loops seems to be inherently limited in promise. The good news is that with each year, the background research and technology is progressing to significantly more sophisticated levels, achieving denser, more accurate and less power-consuming transducer arrays for picking up the tactile features of the environment. As has often been the case before in the history of important prosthesis development, much of the technology for sensory augmentation is to be found in other applications, in this case, industrial automation and robotics. When, as will happen sooner or later, art and technology reach out and come together, the parts of the limb-prosthesis system will indeed, touch—with feeling.

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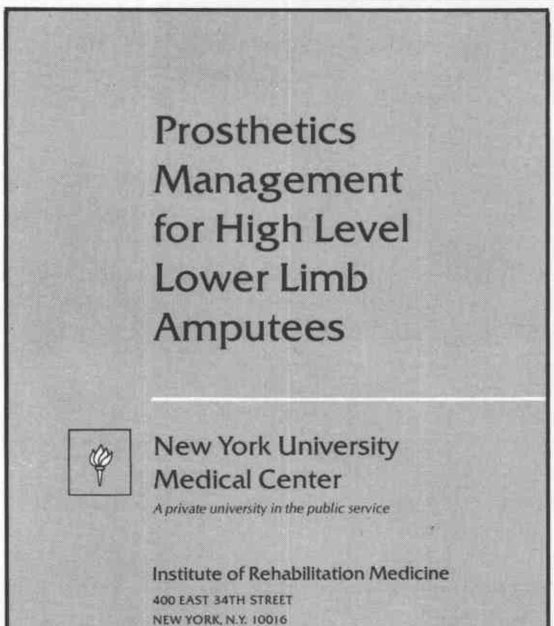

A brochure entitled "Prosthetics Management for High Level Lower Limb Amputees" is now available to our readers free of charge. It may be ordered through Orthotics and Prosthetics, Institute of Rehabilitation Medicine, NYU Medical Center, 400 E. 34th Street, New York, New York 10016.

Winter/Spring Honorarium

Louis Ekus, C.O. has been awarded the $100 honorarium for his article "Cross-Diagonal Closure of Pelvic and Spinal Appliances." Congratulations!