Training Program for a Myo-Electrically Controlled Prosthesis with Sensory Feedback System

(myo-electric prosthesis, functional training)

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A myo-electrically controlled prosthesis that incorporates a sensory feedback mechanism to provide the wearer with a sense of touch or gripping force in the prosthetic hand was developed for patients with below-elbow amputations. A training protocol was established in which patients were taught to produce myo-electric control signals and to interpret the sensory feedback. The protocol includes functional training in daily living skills. The experiences of four patients trained with these limbs are described.

Gerald F. Shannon

In 1966, Gingas and others (1) reported that the Soviets had developed a bioelectric upper extremity prosthesis. The Russians had apparently based their work on the theoretical principles of Basmajian, whose experiments showed that one could single out and control isolated motor units (2). Since the Russian development, much work on myo-electric prostheses has been carried out. Centers in Canada (University of New Brunswick, Ontario Crippled Children’s Center, and Rehabilitation Institute of Montreal), Italy (Hans Schmidl’s work), Sweden (recent work of Dr. R. Sorbye), Britain (work of Battye, Nightingale and Wills at Guys Hospital), and the United States (at MIT, University of Utah, UCLA, CAPP, Rancho Los Amigos Hospital, and Veterans Hospitals) have all made significant contributions.

There is still controversy over the choice between the myo-electric prosthesis and the conventional voluntary-opening hook prosthesis. Trefler (3), who recognized the problem of prosthesis rejection, presented the merits and drawbacks of each control system (myo-electrical, electromechanical, and manual or body-powered) available for upper limb prostheses. She concluded that patient assessment was
the most important factor governing choice given the necessary finances, training time, and skilled personnel. Colburn (4) also examined the use of myo-electric prostheses and concluded that patient rejection was probably related to lack of sensory feedback.

We believe that the myo-electric hand with its exceptional cosmetic appearance and functional capabilities makes a useful substitute for the absent hand and that the application of sensory feedback in the form of touch sensation will further enhance acceptability. Since no electric prosthesis with sensory feedback mechanism to provide the wearer with a sense of touch or gripping force in the prosthetic hand is available, a useful substitute is needed. Colburn (4) also examined the use of myo-electric prostheses in Australia, and since the literature on sensory feedback is sparse, the functional performance of the myo-electric prosthesis with sensory feedback mechanism was investigated.

Four below-elbow amputee subjects were fitted with a myo-electric prosthesis and trained in its use. The prosthesis incorporates a sensory feedback mechanism to provide the wearer with a sense of touch or gripping force in the prosthetic hand. This is a report of that project.

Description of Apparatus

The prosthesis used is an adaptation of the commercially available Otto Bock myo-electrically controlled hand. It provides for a 3-state control of the hand—OFF, CLOSE, and OPEN (5)—and a feedback sensation informing the wearer about the pinch force between thumb and index finger. The feedback is not a feature of the commercial prosthesis.

Myo-Electric Control of the Hand. A surface electrode is applied over a muscle group that the wearer can isolate to produce on demand controlled myo-potentials, electrical signals that result when a muscle is contracted isometrically (7), and that the wearer can also relax at will. These signals can be transmitted via the skin to surface electrodes. They can then be amplified and processed to control the electric motor in the prosthesis. The myo-potentials must not appear when other natural limb movements occur, elbow flexion, for example. In below-elbow amputations, the superficial flexor group of forearm muscles provides an adequate and convenient control site (flexor digitorum superficialis or flexor carpi radialis muscles).

Sensory Feedback. An electrical current is used to supply sensory feedback via a surface electrode (6 mm diameter) applied to the skin over the lateral cutaneous nerve. Because there might be significant client differences in control sites arising from such factors as type of injury, method of subsequent surgical repair, or location of muscles and nerves, a piece of equipment, a myo-electric trainer, is an essential diagnostic component in the selection of control sites, fitting, and successful operation of the myo-electric hand. The trainer that accompanies the Otto Bock prosthesis is designed for two control sites. Since only one site for both flexion and extension is used with below-elbow amputees, another myo-electric trainer was developed. The MyoFeedback Control System Trainer, control electronics, and stimulating systems are described elsewhere (6).

Method of Operation of the Sensory Feedback. Whenever an object is grasped by the wearer of the myo-electrically controlled hand, the index finger is bent. Strain gauges were fitted to the index finger to measure the gripping force exerted at the tip of the index finger. The output from the strain gauge is proportional to the gripping force, and this output is used to control the stimulus generator. The stimulus consists of a chain of pulses of electricity with each pulse lasting 10 msec. Grip is related to the pulse repetition rate— 1 pulse per second gives a slow pulse rate of 1 pulse per second, and, as grip strengthens, this rate increases until a fast pulse rate of 10 per second is reached. When the index finger is not touching anything, there is no stimulus.

Selection of Subjects and Control Sites

Subjects. Because of limited finances and a need to keep the investigation simple, only a few selected below-elbow amputees were fitted with the myo-electrically controlled hand and sensory device. In selecting subjects, consideration was given to: the length of the stump so that a Munster suction socket could be used; the patient's ability to produce suitable control signals and detect the feedback sensation; the patient's ability to attend training sessions; and the patient's general interest in a new form of limb. Two subjects were chosen for the initial training followed by another two subjects 12 months later.

S1. Male, right-handed, 35 years old, with a below-elbow left-arm amputation, who had been wearing a shoulder harness and voluntary-opening hook prosthesis for 10 years. He is a lecturer and uses a cosmetic hand in public. Sensitive to the loss of his hand, he never wears his hook in public, but uses it at home for gardening, playing tennis, and carpentry.

S2. Male, right-handed, 35 years old, with a below-elbow left-arm amputation, who lost his hand as a teenager. He rejected a hook prosthesis soon after receiving it because he found it cumbersome, uncomfortable, and noncosmetic. He is a sales representative, functions well...
one-handed, is well adjusted to the loss of his hand, and his condition is accepted by his friends and colleagues.

S3. Male, right-handed, 43 years old, with a below-elbow right-arm amputation, who lost his hand in his early 20s. He had a course of rehabilitation but rejected a hook prosthesis. He is a sales representative, functions as a one-handed person, but is easily discouraged by failure. He tends to mask the loss of his hand by being extrovert with his friends and with bouts of aggressive behavior. He does carpentry as a hobby and is a bowler at cricket.

S4. Female, right-handed, 45 years old, with a below-elbow right-arm amputation, who has worn a voluntary-opening split-hook prosthesis with proficiency for 3 years. She is a housewife and dependent on her hook in all household activities. She is well adjusted to the loss of her hand but does not wear her hook in public.

Control Sites. Before training was begun, suitable sites for the motor control and sensory feedback electrodes were chosen. For the control site, each subject was seated in front of the Trainer, an electrode was taped to the forearm flexor group of muscles and was moved on this group until a site was found where the subject could produce a myo-potential without fatigue. Sites that produced myo-potentials in the presence of other limb movements, such as elbow flexion, were rejected. The feedback electrode site was found by similar exploration of the stump. The requirement was for the stimulus to be easily detected but cause neither pain nor muscle contraction.

Training

Literature associated with training subjects to use myo-electric limbs is scarce and is limited to the training of normal college students to produce myo-electric potentials (8).

The training program consisted of three stages: 1. pre-fitting, in which the subject learned to produce suitable myo-electric control signals and interpret the feedback sensation; 2. post-fitting, during which the subject learned to use the new limb; and 3. sessions designed to teach the subject to use the arm in the ordinary skills of daily living.

Pre-fitting Training. The patient, seated at a desk on which the Trainer is positioned, places the stump on the desk. The myo-control electrode is placed over the flexor digitalis group of muscles. The patient is asked to look at the meter on the Trainer and relax until the needle returns to near zero. This may require a few minutes to allow for chemico-electrical equilibrium to be established between the skin electrolytes and the metal of the electrodes.

The operation of the Trainer is then explained to the subject. Because subjects have different muscular ability and consequently produce signals of varying magnitudes, variable gain is placed in the amplifier. The subject is asked to produce the full level of myo-electric control, hold the contraction for a few seconds, and relax. This sequence is repeated several times. If this is fatiguing, the gain is adjusted until a comfortable operating level is obtained. The subject then practices producing the three different levels corresponding to OFF, CLOSE, and OPEN. Two practice sessions of one-half hour each normally suffice for this. An electric hand is plugged into the Trainer and the subject has two additional half-hour sessions in which to practice opening and closing the hand.

Next, the stimulating electrode is placed over the lateral cutaneous nerve in the preferred location previously determined. A "test" switch
on the Trainer allows the stimulus signal to be turned on and the level can be adjusted so as to be comfortable to the patient. Stimulus control is then transferred to the hand. The instructor touches the index finger to illustrate that the rate of application of the stimulus pulses varies as the pressure on the index finger varies. The subject then controls the hand to grip various objects and learns to interpret the strength of grip in terms of the pulse repetition rate of the stimulus. Two further half-hour training sessions usually bring subjects to the stage where they are ready to be fitted with the prosthesis.

All subjects were fitted with Munster suction sockets, and the two electrodes were placed in the socket in the identical positions as those determined previously. The prosthesis was pulled onto the stump by means of a thin sock.

Learning to Use the Limb. After an analysis of simple grasp-release tasks, the following skills were identified as those subjects must master: Grasp, place, and release objects of sizes ranging from 70 mm (sandwich size) to 4 mm (diameter of a ballpoint pen), as well as objects such as coins, keys, and small nails. Subjects would also need to appreciate the difference in handling round and square objects and be able to "sense" qualities of textures and different weights in the hand.

To implement the training program, blocks were made in the following sizes: 70 mm, 50 mm, 10 mm, 5 mm—in hard wood, soft wood, polystyrene, and sponge rubber. Wood and steel rod round pegs were also made, all 12 cm long in 7 cm, 5 cm, and 3 cm diameters. Flat, round wooden discs were made in 10 cm, 7 cm, 5 cm, and 2 cm diameters. This equipment gives subjects practice in opening and closing the hand and in learning the effect of different textures on the response of the sensory feedback device (Figure 1).

Developing Practical Skills. The subjects were taken into a kitchen and bathroom where various daily living skills were tried. These included the preparation of a simple meal such as making sandwiches and a cup of tea, and eating a meal with a knife and fork (Figure 2). Dressing activities such as putting on a tie, fastening buttons and belt, and using a zipper presented no
Table 1

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Percentile</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>286</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>242</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>199</td>
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</tbody>
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Perforrnanee over four trials was between two to three times slower than the average nonamputee performance.

Table 2

<table>
<thead>
<tr>
<th>Subjects</th>
<th>(1) Blocks</th>
<th>(2) Nails</th>
<th>(3) Money</th>
<th>(4) Pegs (L)</th>
<th>(5) Pegs (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.4</td>
<td>—</td>
<td>—</td>
<td>25.5</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>8.5</td>
<td>—</td>
<td>—</td>
<td>30.5</td>
<td>—</td>
</tr>
<tr>
<td>Mean (sec)</td>
<td>4.4</td>
<td>6.4</td>
<td>5.4</td>
<td>10.7</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Performance was twice as slow as the average mean in gross tasks (blocks), and two to three times slower in grasping and releasing large pegs.

Table 3

<table>
<thead>
<tr>
<th>Subject</th>
<th>Myo-Electric</th>
<th>Hosmer-Dorrance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (sec)</td>
<td>640</td>
<td>631</td>
</tr>
</tbody>
</table>

There was no appreciable difference in performance time using the two appliances.

Results

During training it was found that certain of the objects could not be grasped. The mechanism of the three gripping fingers of the hand functions as a 3-point chuck grip. The thumb of the hand is rotated rather more than in the normal hand and there is no flexion in the wrist. These two factors, combined with an inability to pronate, enable the hand to grip large round and square objects with relative ease, but small flat objects become awkward and difficult to manage. The smallest object that could be managed with difficulty was a pencil. Flat coins were impossible to pick up in a sitting position, but could be picked up with subjects standing. The larger of the blocks, 70 mm size, could not be gripped.

Re-examination of the normal hand grasping large blocks showed that all the fingers are abducted fully, then the distal interphalan-geal joints flex slightly around the large object to grip it. The artificial hand does not have this ability, since the movement is between the index and middle fingers working as one unit, and the thumb as the second unit. The remaining ring and little fingers follow passively. Since the sponge blocks were soft, the artificial hand was able to get a grip on them. In real terms, this means that a building block, for example, cannot be lifted, but a 500 g block of butter can be handled. Cold and wet milk bottles tended to slip. Plastic lids were impossible to open but subjects quickly learned to turn taps and make sandwiches and cups of tea.

Subjects were anxious to wear their new prostheses at home, and, after 3 days, did so following several minor adjustments. Follow-up visits were carried out at intervals of 3 weeks thereafter. Subjects were given daily diaries to complete and to record their impressions. Two tests were applied at the follow-ups: The Minnesota Rate of Manipulation Test (MRMT); The Placing Test (9); The Smith Hand Function Test; and Uni-
lateral Grasp-Release Tasks (10). The results are presented in Tables 1-3.

Discussion
Specific comments can be made regarding the subjects' responses to their prostheses:

The first subject, who had always worn a cosmetic hand in public and a hook at home, was so pleased with the appearance of the new hand that he wore it constantly, even on occasions when the batteries were dead and the hand was not functioning. He said the feedback was reassuring.

The second subject, who had functioned with one hand for some 20 years, expressed some discomfort with the unaccustomed weight and extra length of the new hand. After 6 months, he experienced a psychological block toward it. He has no difficulty wearing it when traveling on the job, but has difficulty with the unaccustomed weight and extra length of the new hand. After 6 months, he experienced a psychological block toward it. He has no difficulty wearing it when traveling on the job, but has difficulty when meeting friends, and bouts of anxiety when attending social functions. He reports that the sensory feedback enables him to handle objects with confidence.

The third subject uses his limb for part of the day at work, both while in the office and while out seeing clients. He tends not to use it on weekends and does not use it for driving.

The fourth subject wears her hand with great proficiency. She puts it on before dressing in the morning and reports she would be "lost without it." She has tried a variety of tasks with enthusiasm. Among her achievements are changing the baby's diaper, carrying two glasses of beer without a tray, and using scissors. She has been referred to a rehabilitation center for training as a typist.

In the training program, the four subjects quickly learned to master the required techniques for myoelectric control and manipulation of the hand. The grasp-place-release tasks could be improved by an altered starting position. The mechanical construction of the electric hand makes the manipulation of the objects on a horizontal plane difficult. Tasks could be accomplished more comfortably in a vertical plane. Additional training programs will be necessary to accommodate individual needs for work and leisure activities for future subjects.

The validity of the two tests administered is questioned. However, in the absence of a specific test of performance of the myoelectric hand, some measure is needed to compare with that of the normal intact hand.

Acknowledgments
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