# A MULTIFUNCTIONAL HAND PROSTHESIS IN PRACTICE - CLINICAL EVALUATION AND PROBLEMS

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## ABSTRACT

Development of multifunctional hand prostheses has been hampered by the lack of an acceptable control system. In the present project a system for operating six movements in a below-elbow prosthesis has been developed and evaluated. The control method is based on pattern recognition of myoelectric signals from forearm stump muscles.

The amputee's ability to operate the prosthesis has been evaluated in two laboratory tests, which are described below. Furthermore, a clinical evaluation of the prosthetic system used by the amputees at home in their daily life is presented, and our experience concerning problems and technical breakdowns with this system is discussed in the paper.

## INTRODUCTION

During the last two decades it has become common in Europe to supply forearm amputees with electric hands, operated by electric signals generated in the muscles - myoelectric signals. Such motorized prosthetic hands provide prehension and have potential advantages over earlier body-powered prostheses (Herberts, 1969; Soerjanto, 1971; Childress, Holmes & Billock, 1974). It is believed that the functional benefit of this type of device can be considerably improved by additional function being introduced. Prostheses providing prehension, forearm rotation and wrist movements have been developed in a few research centers but today no such prosthetic system is commercially available. One of the main reasons has been the difficult, unsolved problem of how to control an advanced prosthesis in a way that is acceptable to the amputee.

In the development of a control system for a multifunctional prosthesis, the main objective must be to design a system which requires a minimum of training for the amputee to operate all the prosthetic movements in a natural way. In several proposed solutions it has been suggested that a combination of a number of myoelectric signals should be used for control of each degree of freedom. A research group at Moss Rehabilitation Hospital in Philadelphia has developed a method allowing simultaneous control of humeral, elbow and forearm movements (Finley & Wirta, 1967; Taylor & Finley, 1974). The Moss group utilized a pattern recognition technique to identify and discriminate synergistic muscle actions in the back, chest and shoulders. Jacobsen et al (Jacobsen & Mann, 1973; Jacobsen et al, 1975) suggested a method for estimation of torques by a linear combination of myoelectric signals from the shoulder region. The torques make the prosthesis move in the specified way. Lyman et al (1974) have proposed a pattern recognition technique for control of elbow flexing, forearm rotation and prehension. However, no one of these methods has so far been developed and miniaturized to the extent that it has been possible to evaluate the systems on patients.

In our project, a control system has been developed which is based on a pattern recognition technique (Lawrence et al, 1973; Herberts et al, 1973). It is designed for control of a below-elbow prosthesis providing prehension, forearm rotation and wrist movements. The myoelectric signal patterns, picked up on the forearm stump, show considerable individual variations, mainly caused by the different stump lengths and the various ways in which the amputation surgery was performed. It follows that our control system has to be individually adapted to the amputees. The system has now been evaluated in practice on a small series of amputees. Preliminary results and problems are described in this paper.

## METHOD

The method used for control of the three bi-directional movements has previously been described in several papers (Herberts et al, 1973; Almström & Herberts, 1975; Almström, 1977). The perception of the lost hand - the phantom hand - occurring in most upper extremity amputees is fundamental. The phantom phenomenon means that the amputee perceives his lost hand and that he can imagine various phantom movements. Such movements are accompanied by specific muscle contractions, which can be registered by a number of surface electrodes attached to the stump. The myoelectric signal levels registered are specific for each phantom hand movement. The signals constitute signal patterns, which are illustrated in Fig. 1. Six electrodes are used, and the imagined movements are finger flexion, finger extension, pronation, supination, wrist flexion and wrist extension. The information carried by the patterns can be interpreted by means of pattern recognition methods, i.e. the various phantom hand movements related to the patterns can be identified (Lawrence & Kadefors, 1974).

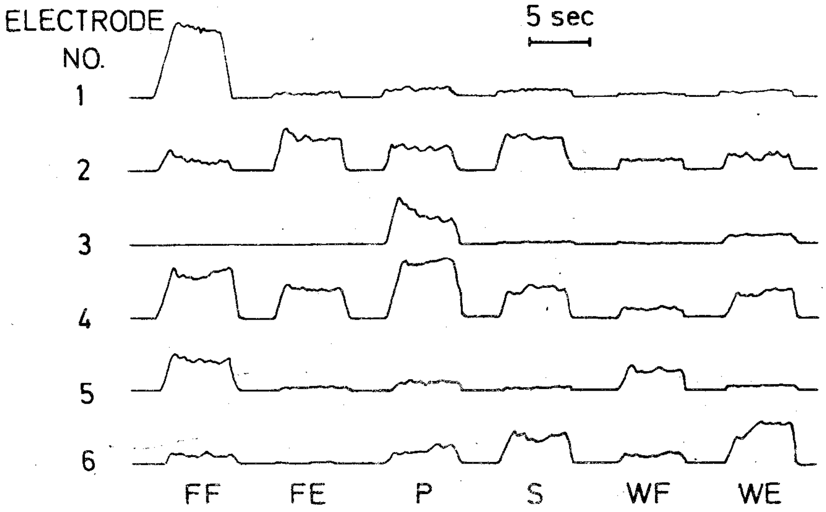

Figure 1. Signal patterns from six surface electrodes. The imagined phantom hand movements performed by the amputee are finger flexion (FF), finger extension (FE), pronation (P), supination (S), wrist flexion (WF), and wrist extension (WE).

The pattern recognition procedure is implemented by an electronic network placed in a portable box. The electronic network is designed after the computer analysis of the amputee's individual patterns.

The control system is adapted to the Swedish hand prosthesis, which provides prehension, rotation and wrist movements (Hägg & Spets, 1973). The movements are activated by three electric DC-motors placed in the forearm part. The prosthesis also provides passive ulnar-radial deviation and thumb rotation. The complete prosthetic system with prosthesis, socket, control unit and battery is shown in Fig. 2.

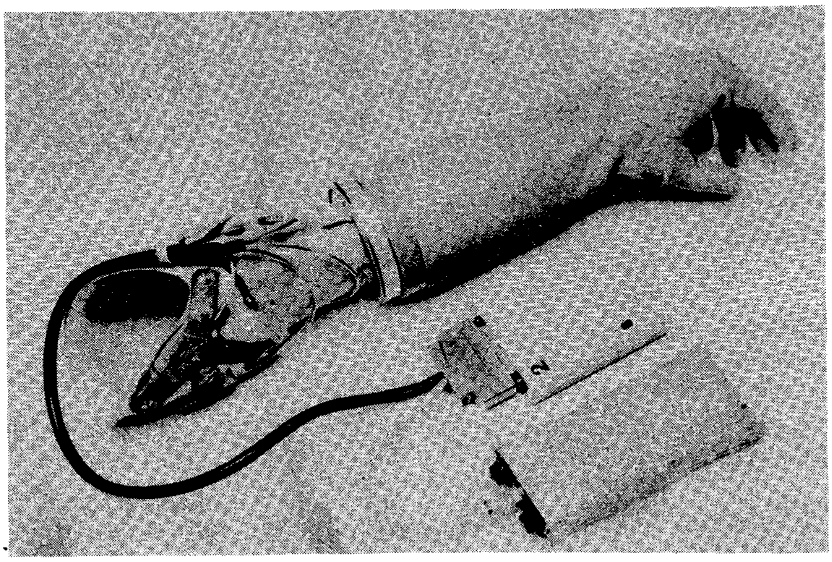

Figure 2. The complete prosthetic system.

## MATERIAL

The prosthesis has been adapted to four amputees for evaluation of the control system. The amputees have not been selected with respect to any specific characteristic except for the stump length. All of them are male and they were all amputated as young boys, as shown in Table I. Two of the amputees use conventional electric hand prostheses daily, one of them uses a cosmetic prosthesis and one of them does not use prosthetic devices at all. All amputees perceive the phantom hand distinctly, but the perceptions show considerable individual variations.

These four amputees have been trained and evaluated at the laboratory and at that time they had no opportunity to use the prostheses at home. After the laboratory evaluation, two of the amputees have been adapted with the prosthesis for use at home and in their daily life. Further three amputees will in a near future be adapted with the prosthesis.

Table I. Age, sex and stump length of the four subjects and type of prosthesis they used before.

| Subject | Sex | Age | Age at amputation | Side of amputation | Stump length (cm) | Type of prosthesis used before |
|---|---|---|---|---|---|---|
| LA | male | 37 | 10 | left | 18 | -------------- |
| FP | male | 37 | 10 | left | 17 | Otto Bock, electric |
| SS | male | 25 | 9 | left | 15 | Otto Bock, electric |
| ME | male | 33 | 11 | right | 19 | cosmetic |

## EVALUATION PROCEDURE

The first part of the evaluation was performed in the laboratory. The subjects were evaluated with respect to their ability to control each specific prosthetic movement as well as to their ability to operate the prosthesis in activities of daily life (ADL). For this purpose, two different methods were employed for the evaluation: an objective computer test and an ADL-test.

In the computer test the subject is asked to perform the basic prosthetic movements. The output signals from the pattern recognition unit to the prosthetic motors are recorded by the computer. Hence, requested and inadvertent movements classified by the pattern recognition unit are registered. The subject is asked to start each movement on a specific command. The computer recording starts at the same time as the command is given, and is stopped when the requested movement is completed. The computer calculates the fraction of the completion time in which requested and inadvertent movements are classified. The results yield the rate of correct recognition of the myoelectric patterns.

All the subjects were evaluated twice with this test. The first time was immediately after the application of the prosthesis. Then the subjects were trained by an occupational therapist twice a week for two months. After the training period, the ADL-test was performed on three of the patients, and then the subjects were evaluated with the computer test the second time. Subject ME was not evaluated with the ADL-test, and he had just a short training period before the second computer test. The subjects did not have the prostheses at home, which meant that they could use the prostheses on the training and test occasions only.

The ADL-test, which was developed by a group in Sweden (Wärnberg, Andersson & Rydell, 1973), includes 50 activities from various fields, such as feeding, clerical work, house work, and light assembly work, see Fig. 3. The activities are constructed in such a way that both hands must be used simultaneously for the subject to achieve a normal pattern of working, without compensatory movements. The performance is carefully observed and registered, particularly with respect to the use of active prehension, pro-supination, and wrist flexion-extension.

The amputees who have been fitted with the prosthetic system for use at home are carefully followed up with respect to how they use the prostheses. In order to register the number of times the various active movements are used, counters are mounted in the prosthesis (Hägg et al, 1975). The counters

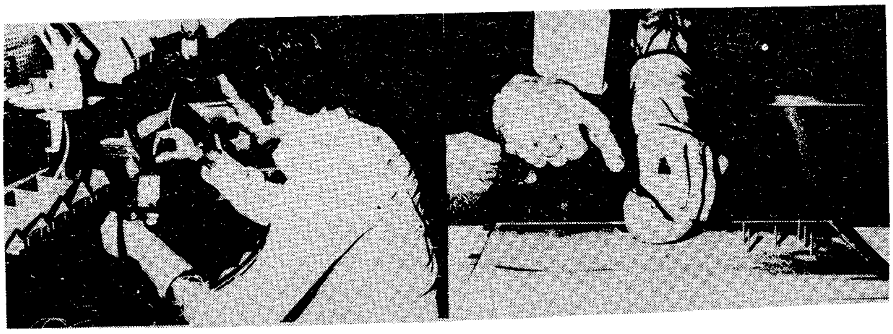

Figure 3 (a) and (b). Amputees operating the prosthesis.

are read once a week the first month, then monthly. The amputee's subjective experience is examined in interviews. The amputee is asked how often he uses the prosthesis (number of days per week, hours per day, etc.) and what kind of problems he has had using the prosthesis (control problems, technical breakdowns, charging batteries, etc.). The interview is performed monthly. The way the amputee uses the prosthesis is also studied by means of the ADL-test after one, three and six months.

## RESULTS

### Computer test

The results from the computer tests are shown in Table II. The amputees performed each movement about 50 times and the mean value of the fraction from all amputees and all movements are given in the table. Since simultaneous movements can be performed, the sum of the fractions may exceed 100 per cent for a requested movement.

The rate of correct recognition is high already before training. Except for wrist flexion, the rates of correct recognition for requested movements are 90 per cent or more. After training these rates are slightly improved and they all exceed 90 per cent. Inadvertent movements occur in some cases. The fractions that such movements are identified are never exceeding 25 per cent and in most cases they are zero or completely negligible.

Table II. Rate of correct recognition.
B - before training, A - after training.

| Requested movement | Classified movements | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FF | | FE | | P | | S | | WF | | WE | |
| | B | A | B | A | B | A | B | A | B | A | B | A |
| FF | 94 | 100 | 2 | 0 | 0 | 0 | 1 | 0 | 10 | 0 | 16 | 0 |
| FE | 0 | 0 | 93 | 97 | 0 | 0 | 3 | 14 | 0 | 0 | 25 | 0 |
| P | 0 | 0 | 8 | 0 | 96 | 98 | 4 | 2 | 20 | 1 | 3 | 0 |
| S | 2 | 0 | 14 | 10 | 0 | 0 | 98 | 91 | 0 | 0 | 24 | 24 |
| WF | 0 | 24 | 2 | 0 | 0 | 10 | 0 | 0 | 74 | 97 | 0 | 0 |
| WE | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 90 | 96 |

## ADL-test

In Table III the results from the ADL-test are presented. None of the subjects performed all of the fifty activities, since implements were not available to carry out some of the tasks. The number of times that the subjects used the various prosthetic functions and the number of times they used the prosthesis as support or performed compensatory movements are given in the table.

As illustrated in Table III, the active prosthetic functions were frequently used. Besides the prehension, which was used in most activities, the active wrist flexion-extension and pronation-supination were used in approximately 80 per cent of the tasks. Compensatory movements were performed in few activities; subject FP did not perform any such movement. Subjects LA and FP were unable to perform one and two activities, respectively.

Table III. Result of the ADL-test. Number of times the various functions were used.

| Number of | Subject<br>LA | <br>FP | <br>SS |
|---|---|---|---|
| activities performed | 47 | 44 | 45 |
| active prehension | 45 | 40 | 44 |
| wrist flexion-extension | 35 | 35 | 38 |
| pro-supination | 37 | 35 | 39 |
| passive ulnar deviation | 1 | 3 | 2 |
| compensatory movements | 4 | 0 | 5 |
| times used as support | 1 | 3 | 2 |

## Follow-up study of amputees using the prosthesis at home

Since the amputees have had their prostheses less than four months, the results from the follow-up study are not yet available. The number of movements registered, so far, by the counter shows that the prosthetic movements are used, particularly the prehension and the rotation. One of the amputees reports that he cannot use the prosthesis more than three to four hours a day because the socket does not fit. A new socket is now manufactured for this amputee. ADL-tests have shown that the amputees have gained more experience in using their prostheses.

## PROBLEMS AND TECHNICAL BREAKDOWNS

During the first laboratory tests and during the time the prosthetic system has been in permanent practice, some problems and breakdowns have occurred. This can be summarized as follows:

1. Socket manufacturing.
2. Wiring and mechanical breakdowns in the prosthesis.
3. The control electronic unit including the cable to the prosthesis.
4. The glove.

The most important properties of the socket are the perfect fitting to the stump and a stable fixation to the elbow under normal dynamic circumstances. Furthermore, the electrodes mounted in the socket must be accurately and stably located to yield an optimal pattern. It is a complicated and time consuming procedure to manufacture such a socket. A socket similar to the Münster-socket has been used in the first applications. This type of socket has, however, drawbacks, since as many as six electrodes are mounted in the socket and arising from their locations, the socket design hampers the elbow movement. Other types of sockets are, however, under development.

During the laboratory evaluation, technical breakdowns occurred frequently. The wiring in the prosthesis was one of the weak parts. Particularly the wires at the rotation interface between the socket and the prosthesis have broken down several times. The rotation movement and the wrist flexion-extension movement are stopped at end positions by microswitches and mechanical stop lugs. Unless the microswitches are correctly adjusted relative to the stop lugs, they will be exposed to high forces which may cause breakdowns.

One of the weak parts in the system is the cable with the contact to the electronic control unit, which has caused some failures. A system where the control unit is placed in the prosthesis is now under development. This will eliminate the cable and the contact and hence the cable breakdowns can be reduced.

The electronic control unit has not been exposed to breakdown. Reliable electronic components and the plastic box provide a reliable unit. Neither the battery unit has caused any problems. The fuses are blown sometimes, but the amputees can easily change them.

The outer shell on the prosthesis is a PVC-glove which should protect the mechanism from water and dirt and provide a cosmetic appearance. The manufacturing of gloves to particularly multifunctional prostheses is difficult since a thick glove, which is reliable, hampers the prosthetic movements - the movement force and speed will be reduced. Hence there must be a compromise between movement force and speed and reliability of the glove. The experience from the glove used at present is that the reliability is acceptable, since the glove can easily be changed at the prosthetic workshop.

## DISCUSSION

One major problem with respect to multifunctional hand prostheses is how to control such a complicated device. It is virtually impossible to control several degrees of freedom with isolated myoelectric signals unless the operator is well-trained and concentrated upon the task. The objectives in the design of a control system must be to provide the amputee with a system where the prosthesis can be operated at a subconscious level after a short training period. If the control system is designed so that the remaining muscles are used in the same mode as they functioned before amputation, the amputee perceives the control of the artificial limb as similar to the control of the limb he has lost. With the pattern recognition method used within this project, such a control system can be implemented. The system is individually adapted to the amputee, in contrast to other systems where the amputee has to learn how to operate the prosthetic movements.

In the application procedure a research center with good basic resources in medicine and engineering is required. A digital computer must be employed for the pattern analysis and to simulate control. The pattern analysis must be performed carefully to minimize the frequency of recognition errors. The socket fitting to the arm stump is of great importance for successful application. The fabrication of the socket is time consuming and in general several sockets must be made before acceptable fit and electrode locations are obtained.

The laboratory evaluations have shown that the amputees obtain high rates of correct recognition even before training, i.e. they can reproduce the patterns immediately after application. Some inadvertent movements were observed during the computer tests. These movements were, however, from a functional point of view, non-detrimental. In the training, the subjects acquired patterns of movements, e.g. flexing the wrist at the same time as grasping an object on the table, which appeared very natural and is believed to be the cause of the inadvertent movements.

The ADL-test has shown that in the laboratory all amputees frequently use all active functions. Forearm rotation and wrist flexion-extension are used to position the hand which involves that the amputee can exclude compensatory movements. The rotation and wrist movements are natural and provide improved cosmesis, which to many amputees is more important than functional benefits.

In the course of the laboratory evaluation, only two prostheses which could be mounted on any of the individually adapted sockets were available for use in the project. Consequently, none of the amputees had the opportunity to use the prosthesis regularly at home. Since then a series of new prostheses has become available to our laboratory; two amputees have the prosthetic system at home for daily use and further amputees will be fitted with the system. A follow-up study of the amputees is now performed but the results are not yet available. In this study the subject's opinion of the prosthetic system will be examined since the final acceptance of complicated technical aids is difficult to estimate (Höök, Finnstam, Wager & Wannstedt, 1973).

A severe drawback in present prosthetic systems is the complete absence of sensory feedback. When operating the prosthesis, the amputee must use his eyes and to some extent the noise and the vibration in the device to be aware of position and movements of the prosthesis. It is believed that sensory feedback will improve the functional value and facilitate an accurate control of a complicated prosthesis. Promising efforts are being made to solve this great problem (Anani, Ikeda & Körner, 1977a; Anani, Ikeda & Körner, 1977b).

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