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Experience with Swedish Multifunctional Prosthetic Hands Controlled by Pattern Recognition of Multiple Myoelectric Signals

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Summary. *Clinical experience with two types of multifunctional prosthetic hand, controlled by pattern recognition of multiple myoelectric signals is reported. The prostheses have been used for between one and five years by five patients. The pattern recognition control system enabled the patients to control six separate movements accurately after a short period of training. One of the tested prostheses, the SVEN-hand, was not reliable enough to allow clinical use outside the laboratory. The ES-hand, a second generation multifunctional prosthesis, has promising features, being self-contained and fast moving. It is concluded that multifunctional prosthetic hands help amputees to avoid tiresome and awkward compensatory movements. Their scope, however, does not extend beyond that of conventional myoelectric prostheses. Their combined movements are cosmetically more appealing than a single three-point grip. In order to gain wider acceptance, multifunctional prosthetic hands must reach a stage of development comparable to conventional myoelectric devices particularly with regard to weight and compactness. A pattern recognition control system is essential to the design.*

Résumé. *Les auteurs rapportent l'expérience clinique de deux types de prothèses multifonctionnelles de la main, contrôlées par un système de reconnaissance de signaux myoélectriques multiples. Ces prothèses ont été utilisées par cinq sujets pendant un à cinq ans. Le système de contrôle de reconnaissance permet aux sujets de maîtriser six gestes différents après une courte période de formation. Une des prothèses, la «SVEN-hand», n'est pas suffisamment fiable pour permettre son utilisation en dehors du laboratoire. La «ES-hand», prothèse multifonctionnelle de seconde génération, est prometteuse, étant rapide et autosuffisante.*

On peut en conclure que les prothèses multifonctionnelles de la main aident les amputés à éviter des gestes compensatoires fatigants et maladroits. Cependant, leurs performances ne sont pas supérieures à celles des prothèses myoélectriques classiques. Mais, du point de vue esthétique, leurs gestes complexes sont plus satisfaisants qu'une prise à trois points. Pour pouvoir élargir leurs champs d'application, les prothèses multifonctionnelles de la main devraient atteindre un degré de perfection comparable à celui des dispositifs myoélectriques classiques, surtout en ce qui concerne le poids et la miniaturisation. Un système contrôlant la reconnaissance d'un schéma est essentiel pour la conception d'un tel type de prothèse.

Key words: *Myoelectric prosthetic hands, Pattern recognition, Clinical evaluation*

Multifunctional prosthetic hands allowing grasp, forearm rotation and wrist flexion are widely accepted to be of value in the rehabilitation of below elbow amputees. Several attempts to develop multifunctional hand prostheses have been made [4, 8, 10, 12, 15, 17]. Up to now there have been two major obstacles to the successful use of these devices, firstly, the failure to construct a reliable, light, and self-contained prosthesis and, secondly, difficulty in achieving control of multiple movements.

A new approach to the control of multiple prosthetic movement was introduced by Finley and Wirta [3]. Their method for controlling an arm prosthesis was based on pattern recognition of multiple myo-

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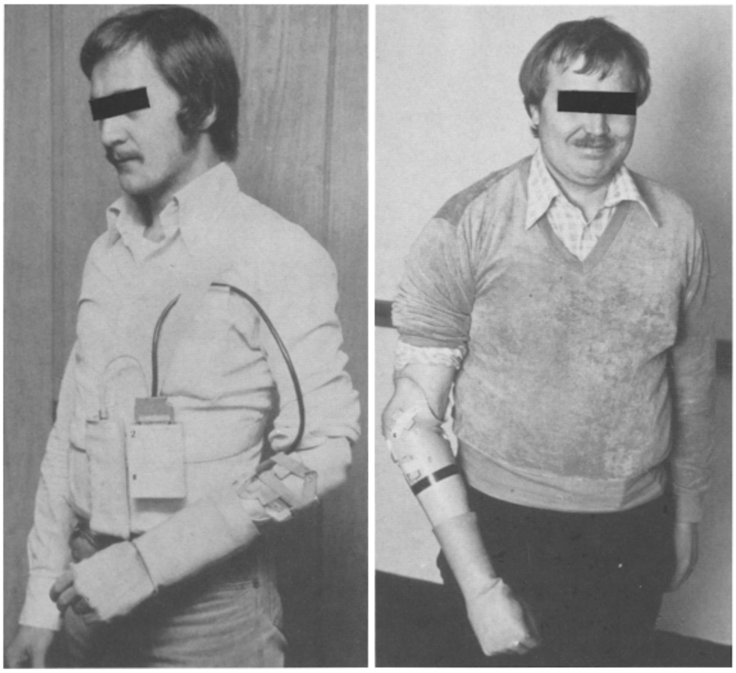

Fig. 1. The two tested prosthetic hands worn by patients, the SVEN-hand *(left)* and the ES-hand *(right)*

electric signals generated in the back, chest and shoulder [19, 20]. Since then pattern recognition has been developed and modified for the control of multi-functional prosthetic hands by Herberts et al. [5]. A clinical study of a Swedish multifunctional hand prosthesis controlled by pattern recognition has been reported by us [6].

The pattern recognition approach for the control of myoelectric prostheses is based upon perception of the phantom hand. Almost all amputees perceive and move their lost hand to some extent. Such movements are accompanied by specific muscle contractions which can be registered by a number of surface electrodes attached to the forearm stump in the prosthetic socket. Each movement yields a specific pattern of myoelectric signals. Six electrodes are used and the imagined movements are finger flexion and extension, pronation and supination of the forearm, and wrist flexion and extension. The various movements can be identified by discriminant analysis of the signal pattern from the electrodes. The analysis is carried out by an electronic network connected to the prosthesis and carried by the patient. Thus the imagined phantom hand movements are transferred to the corresponding movements of the prosthesis.

The present paper reports our further experience in the use of the Swedish multifunctional hand (the SVEN-hand, [8]) controlled by this method. Preliminary results with a second generation self-contained multifunctional prosthetic hand (the ES-hand [10]) are also reported. The two prosthetic systems are shown in Fig. 1.

Material and Methods

Five male patients (below elbow amputees and all experienced users of conventional myoelectric prostheses) took part in the trial (Table 1). The patients were selected if their amputation stump and

Table 1. Details of patients

Age	Amputation side/ dominant side	Stump length (cm)	Year of amputation	Cause for amputation	Prosthesis normally used
LA 40	L/R	17	1950	Accident	None
BJ 24	L/R	11	1973	Accident	Conventional myoelectric to a high degree
HJ 27	R/R	20	1976	Tumor	Conventional myoelectric to a high degree
FP 39	R/R	17	1952	Accident	Conventional myoelectric to a high degree
SS 27	L/R	15	1961	Accident	Conventional myoelectric to a high degree

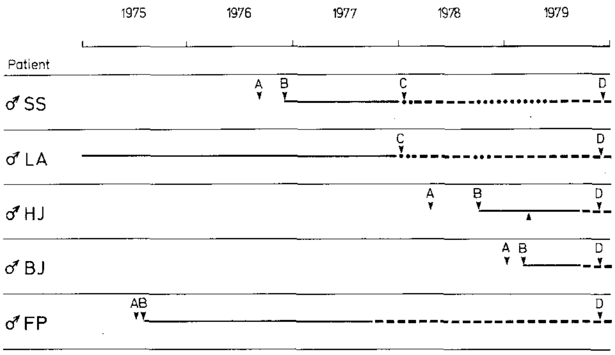

Fig. 2 A–D. Diagram showing the period of participation of each patient in the project. **A** Introduction of the project; **B** Start of regular training; **C** Prosthesis available for use at home; **D** Interview. *Unbroken lines:* regular training at the laboratory; *Dashed lines:* prosthesis not available; *Dotted lines:* use of prosthesis at home

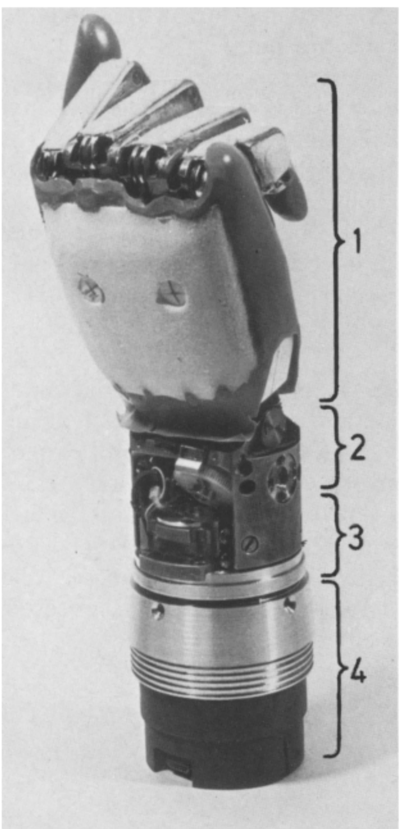

Fig. 3. The ES-hand without glove showing the modules for grip *(1)*, wrist movement *(2)*, forearm rotation *(3)* and the control module *(4)*

general physical and psychological condition were considered acceptable. The prostheses were applied to the patients according to a method previously described [6].

Two patients were supplied with prostheses for use at home, whilst the remaining three could use their prostheses in the laboratory only, owing to shortage of prostheses. Each patient used his own individually made prosthetic socket. The extent of training and use of the multifunctional hands in the case of each patient is displayed in Fig. 2.

In December 1979, after clinical testing was considered finished, all patients were interviewed by the independent author (L. K.) about their experiences. In order to obtain an objective estimate of the patient's use of the prosthesis and its various movements, a miniaturized electronic event counter [9] was built into the two prostheses that were used at home. The number of movements used during four different periods of one week was counted. The patients had been previously informed of this for ethical reasons.

One of the patients was supplied with the recently developed ES-hand [10]. The ES-hand is completely self contained, even in its multifunctional version. It is constructed of modules which are exchangeable for servicing. Depending on the number of functions required, one or two modules can be omitted from the prosthesis. The modules tested in the multifunctional hand were: (a) A prosthetic hand module for prehension, (b) A wrist module for dorsal and volar flexion, (c) A forearm module for pronation and supination, (d) A control module with the electronic pattern recognition control system, and (e) the battery module. The modules are displayed in Fig. 3.

Results

As shown in Fig. 2., all five patients had ceased using or training with their multifunctional SVEN-hands at the time of interview. Four of them were using their conventional myoprostheses and one no prosthesis at all. The testing of the ES-hand was temporarily suspended in order to allow further technical development. The reason for the interruption in training and use of the SVEN-hand was due to technical and mechanical problems. With extensive use they frequently needed repairing and so training was interrupted. This resulted in loss of motivation amongst the patients, especially the two using their prostheses at home. The clinical application of the SVEN-hand must therefore be considered a failure.

The failure of the SVEN-hand resulted in the testing of the ES-hand on one patient. This prosthesis was tested in the laboratory only and, up to now, it has been used for a total of twenty hours. The first impressions of the prosthesis are most favourable. It is self-contained and has a good appearance, which is comparable to that of a conventional myoelectric prosthesis. The movements are faster and the range of each movement is greater than in the SVEN-hand. Its weight is similar to that of the SVEN-hand. During testing no serious electronic or mechanical problems occurred and the patient was satisfied with the device. The most serious disadvantage was its weight and distally placed centre of gravity.

The hand is now in the final stages of development for future commercial production.

As all the patients taking part in the trial had been faced with the clinical failure of the SVEN-hand, there were some difficulties in evaluating their opinions of multifunctional prosthetic hands controlled by pattern recognition. When interviewed they were asked to presume that the specific technical problems encountered with the SVEN-hand could be solved in other multifunctional prostheses.

At interview three patients stated that a multifunctional hand would be of use at work or in the home. They would be prepared to use the prosthesis in their daily lives on condition that it could be given the same degree of reliability and compactness as their conventional prostheses. Two patients were not convinced of the usefulness of a multifunctional prosthetic hand. No patient stated that the multifunctional prosthesis enabled him to do things he could not do with his conventional prosthesis.

The additional degree of freedom with a multifunctional hand prosthesis eliminates the need for compensatory movements in the back and shoulder. This fact was recognised by all five patients. The two patients who stated that they had no use for the multifunctional hand felt that compensatory movements were a minor problem.

Four out of five patients stated that forearm rotation was the most useful movement after grip. This is corroborated by the results from the event counter (Table 2). In two patients rotational movements greatly outnumbered wrist flexion and extension and in one patient rotation was used more than grip. The absolute number of movements varied greatly between different patients and periods. Table 3 shows the absolute number of movements performed by one patient during a single period.

The SVEN-hand weighs about 1050 g. All patients felt that the relatively high weight of the prosthesis caused irritation of the amputation stump after prolonged and uninterrupted use. There were, however, no serious socket problems since the application of multifunctional hands demands meticulous manufacture of the socket in order to achieve stable electrode conditions. No patient experienced skin irritation from the thirteen brass electrodes in the socket.

Table 3. Absolute number of movements performed by patient (SS) over a period of 24 h

Movement	Total	Movements/hour
Grip	1131	47
Rotation	1398	58
Wrist Flexion/extension	128	5

Four of the five patients stated that control of the prosthesis was easily achieved. One patient felt that control was fairly easily learned but that it was quickly lost after a period of disuse. All the patients agreed that regular use of the prosthesis was essential to perfect control. The two most difficult control functions were found to be separation of grasp from wrist movement and precision in forearm rotation. Despite these dificulties all patients were satisfied with the function of the control system. The patients appreciated the use of the phantom image as a method of prosthetic control since this method was already well known to them from their use of conventional myoelectric hands. However, four of the five patients had to modify their phantom image of movement somewhat when changing from conventional to multifunctional myoelectric hands.

All the patients operated their conventional prosthetic grip at a subconscious level. This was not possible with the multifunctional hand owing to the problem of separating grip from wrist movement. Three patients complained that their phantom image of movement was less natural when operating the multifunctional hand than with the conventional one. Proper positioning of the hand without compensatory movements required concentration from all the patients.

A serious problem in control of the prosthesis was the feeling of amputation stump fatigue which developed after intensive use of the prosthesis. Fatigue appeared after between five and thirty minutes of uninterrupted use. This was experienced as an unpleasant numbness in the stump. When fatigue was marked, the separation of patterns decreased and prosthetic control deteriorated. Fatigue disappeared, however, with a few minutes rest.

Table 2. Results of the event counter (home use). The four periods were taken over one week. The distribution of movement is expressed as a percentage of the total

Patient SS						
Movement	Period I	Period II	Period III	Period IV	Mean	SD
Grip	42.6	33.0	22.5	29.1	38.1	8.4
Rotation	52.6	57.1	70.7	64.3	61.2	8.0
Wrist	4.8	9.9	6.8	6.6	7.0	2.2

Discussion

The acceptance of prosthetic devices is a complicated process involving several factors [11]. It has been pointed out by Childress [2] and confirmed by us [1] that the essential pre-requisites to prosthetic acceptance are compactness and reliability.

It is no surprise, therefore, that our experienced prosthesis users rejected the SVEN-hand. This prosthesis is neither reliable nor are the power source and control circuits contained within the device.

The first clinical application of a myoelectrically controlled hand prosthesis appeared in the early 1960's [13]. It was not until more than ten years later that its large scale clinical use was reported [1, 14, 18]. With this history it is not surprising that the SVEN-hand, a first generation multifunctional prosthesis, failed. The reasons for technical failure are basically the same as those which dogged the earliest conventional myoelectric hands. We have great confidence that the present technical problems can be overcome relatively quickly. The ES-hand, although not yet perfected, represents the first step towards a second generation of multifunctional prosthetic hands.

The results recorded on the event counter, reinforced by the patients' own opinions, show that forearm rotation is the most useful movement in the positioning of grip. Probably the event count over-estimates the use of forearm rotation since a rotational movement in the SVEN-hand is quite fast and the prosthesis is operated in an on-off mode. Thus, because of initial lack of precision, the inexperienced prosthesis user may employ an excessive number of movements to position the hand correctly. A proportional control system will probably eliminate this problem as may extended training. Experience with manually controlled rotation shows that an active rotation function is necessary for acceptance. Passive rotation is no better than compensatory movement. Combined movements are also cosmetically much more appealing than a single stiff three-point grip.

Two of our five patients found no advantage in abandoning compensatory movements essential in the use of conventional myoprostheses. However, if multifunctional prosthetic hands are offered in the first instance to recently amputated patients who have not developed compensatory movement habits, then the appreciation of multiple movement will probably increase.

The limited range of wrist movement in the SVEN-hand may account for the low use of wrist motion. Volar flexion is only 20 degrees and the limited range of motion often necessitates compensatory movement in addition to myoelectric wrist volar flexion in order to position the grip correctly. In this situation the amputee often prefers to dispense with volar flexion by shoulder movement to position his grip. This has been taken into consideration in the ES-hand which has a greater range of motion.

No patient complained of socket problems. The manufacture of sockets for multifunctional prosthetic hands controlled by pattern recognition with six myoelectric signals requires much skill and precision from the orthotist. Our experience shows that it is possible to meet these requirements completely with present day socket techniques.

According to the opinion of our patients, the pattern recognition control system is the best part of the prosthesis. All patients found it relatively easy to control all six functions and with regular use the patients became enthusiastic about the good control of the prosthesis. The control system has been technically reliable. With modern micro-computer technology it could be miniaturized further to reduce weight and to allow a self-contained prosthesis. Furthermore, when in the future, a proportional control signal for all movements is developed, micro-computer technology will allow complete miniaturization. In order to fully utilise the advantages of proportional pattern recognition control of multifunctional prostheses some sort of feed back mechanism will probably be necessary [7].

The ease of controlling multiple movements with pattern recognition stems from the use of phantom perception as a reference for the various movements. The extent to which the phantom image can be used for this purpose depends upon training and upon the location of the myoelectric receiving electrodes.

All five patients used their conventional myoelectric grip at a subconscious level which was not the case with the multifunctional hand. These difficulties can be explained partly by lack of training. We believe that a more important factor is the location of the myoelectric receiving electrodes. In order to obtain a clear separation between patterns especially between grip and wrist motion, the usual electrode positions for grip in single function prostheses could not be adopted. The new positions of the electrodes means that a different phantom image of movement must be used for grip control. In most patients grip was opened by extending the thumb and closed by flexing the little finger. These phantom images are, of course, less natural and hence more difficult to transfer to a subconscious level compared to the simple opening and closing grip. Electrode locations that permit control of the prosthesis through natural movements of the phantom image will significantly decrease control problems. Our recent experience shows that pattern separation is also possible when natural phantom perception is used for control.

In patients with weak signals, where signal separation cannot be combined with a natural phantom image of movement, it is probably a better solution to exclude active wrist movement, altogether, than to teach the patient an unnatural method of control. The ability to operate grip at a subconscious level is greatly appreciated by the patient and important for acceptance. Furthermore, the event count shows that wrist movements were used to a small extent by our patients.

The feeling of fatigue in the amputation stump after prolonged operation of the multifunctional hand seems to pose a serious problem. Fatigue changes the myoelectric signals so that the pattern cannot be recognised correctly. If the aetiology of fatigue is accumulation of metabolites in the muscles of the stump then probably it can be decreased by further training. There is, however, a possibility that fatigue is a reflection of an abnormally increased sense of effort caused by the lack of tonic inhibition from the missing hand [16]. If this were the case, inhibitory stimulation would be the remedy. A study of the problem of fatigue is in progress at our laboratory.

Conclusions

Our experience shows that there is a definite need for multifunctional prosthetic hands. This need is greatest in amputees who have not already become accustomed to compensatory movements or who, for some reason, are unable to perform them. Multifunctional prostheses will not be accepted unless they reach the same technical level of development as the commercially available conventional myoelectric devices. Experience with the control system is very promising and further development with the aid of microcomputer technology will allow miniaturization and proportional control.

In order to make control easy to learn it is necessary to refine the receiving electrode positioning and to increase pattern separation between grasp and wrist movement whilst maintaining the phantom image of natural movement as a reference for control. When poor signal separation exists it is probably best to exclude active wrist movement from the prosthesis. The socket manufacturing techniques of today seem to be adequate for the successful use of multifunctional prosthetic hands. Preliminary testing of the multifunctional ES-hand has been very promising. This self-contained prosthesis features fairly fast movement and should be well suited for further trials after further technical development.

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