MEDICAL EVALUATION OF THE BELGRADE ELECTRONIC HAND

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Summary

The interactions between the human being and the machine are manifold but rarely are they of such complex meanings as in the case of the functional-cosmetic substitute of the parts of human body with various mechanical devices. This article represents an approach to the problem of evaluation of the Belgrade electronic hand from the psychological, medical, and technical aspects, with emphasis on the human factors in the relationship between the human being and the machine. In this article, the program and method of evaluation are described; also the results are submitted upon which certain conclusions concerning the functional abilities of the Belgrade electronic hand are made, as well as on general feasibility of applying the described method of evaluation to various types of externally powered hand prostheses.

Introduction

The human arm, particularly the hand, by its complex functionality, undoubtedly represents a highly differential, very important part of the human body.

In addition to the basic function of grasping in different modes, the hand is also capable of accomplishing various very complicated activities in all positions of the arm with respect to the body, engaging the indispensable minimum of consciousness. The information on shape, weight, size, and other qualities of the grasped object can be obtained directly by the hand, without use of other senses and information from elsewhere. The hand is in a certain way the projection of the brain that can be realized at the best from its association with the written or spoken word, and thus with intellect, too.

The function of the hand contains many aspects of duality: static and dynamic, motor and sensory, that must always act harmoniously to achieve the appropriate activity in the best way. Thus, the fourth and fifth finger play an essential role in holding and static control, while the first, second, and third fingers participate as a dynamic tripod whereby the use of precise instruments and various rotating tools is possible. All the activities proceed spontaneously whereby the sensory control of the hand when knowing the operating procedure, essentially effects the regularity, ease, and speed of operation.

Loss of one arm or any of its parts represents always a very hard invalidhood, bringing serious functional difficulties as well as causing a series of disturbances in the person. The problems that arise are frequently more of a psychological than of a mechanical character.

Design of prosthetic devices that would substitute for the lost human hand most adequately has been a matter to which many efforts and systematic studies have been extended in the field of prosthetics. The trend has been to make such a terminal device that would, by its shape, size, and color, weight, and its consistency, imitate the hand successfully, but simultaneously possess a definite functionality so that besides its purely aesthetic requirements it could be used also as a tool for useful work. Therefore, the tasks a designer encounters are numerous and complicated, and for many problems encountered in treating this matter, definite satisfying solutions have not yet been found. So the lack of tactile felling of the prosthetic hand requires a need for constant visual control of coordination to acquire experience in operation. This most delicate problem has not been solved so far, though just now the work on its realization is intensively on the way.

Today there exists a great number of prosthetic hands in the world. Besides those that operate on the principle of mechanical pull and require a considerable physical effort because a great portion of the produced power needed for operation is lost on the path to the terminal ending, there are several efficient externally powered systems that by their structure, technical advantages and functional possibilities exhibit a real progress in the field of providing prostheses for persons with upper-extremity amputations.

The Belgrade Electronic Hand

The Belgrade electronic hand, the evaluation of which has been completed, by its essence belongs to the group of prostheses for which the power needed for operation is brought from an external source. The current solutions in the field of electronics and automatic control have been practically applied to its internal structure. The complete Belgrade hand has electric parts with logic circuits, an electrical motor and battery whose basic task is to select the type of grasping, speed regulation of the selected movement, and strength of squeeze. The mechanical part with the hand-body and fingers is, by its appearance, number of phalanxes, way of functioning, and domain of movability in the interphalangeal and metacarpal-phalangeal joints, similar to a normal human hand. By introducing the spring system into the finger pulling mechanism, a certain degree of flexibility in the adaptive grasping, according to the object shape that is to be grasped, has been attained. The thumb is placed at an angle of 45 degs, approximately, with respect to the plane of other fingers and slightly rotated around its longitudinal axis.

The mechanism for driving the fingers has a gear transmission that enables the hand to remain in the same position even after the motor has stopped its operation. This means that the already taken position cannot be changed by some external action. The thumb and all fingers are driven by a servo-motor that is the executive element of the prosthesis. The hand prosthesis system has been designed so that it operates by means of signals from a potentiometer located on the back of the amputee by means of a figure eight-type harness, (control mode I), as well as by means of transducer elements containing a mixture of rare earth (lanthanides) electrically sensitive to the variations in pressure force (control modes II and III). The signals are generated by the patient's movement in the sense of scapular abduction and adduction. The control system achieves the voluntary control of hand opening and closing by the proportionate control of grasping force and speed.

Such a design of the Belgrade electronic hand has been worked out in the last two years to such an extent that it could be subjected to a detailed technical and medical testing.

Methodology

In April 1968, the work on the evaluation of the Belgrade electronic hand started at the Center for Orthopaedic Prosthetics, Beograd, with the cooperation of experts from the Committee on Prosthetics Research and Development, Washington, and the Mihailo Pupin Institute, Beograd. The schedule for this work was made, and the methodology of the evaluation procedure determined.

The purpose of the medical evaluation was the appraisal of the real possibilities and functional capabilities of the Belgrade electronic hand applied to patients with upper-extremity amputations at various levels. The evaluation method is based on comparing the Belgrade electronic hand with carefully selected types of mechanical hands in the first phase, and with electromechanical ones in the second phase. The selection of the mechanical hands was based on their satisfactory properties with respect to structural simplicity and functional possibilities. These types of hands have found wide application not only as substitutes for the lost hand in forearm amputations and disarticulations in the hand joint, but also for amputations at other levels. The mechanical hands of the Dorrance type, operating on the principle of voluntary opening, and the APRL voluntary closing-type hand have been used in the evaluation.

From the group of elecromechanical hands, the types chosen were the Viennatone and Montreal, Canada hands. It is known that the Viennatone hand so far has been applied exclusively with the forearm amputation which suggests limitations in proceeding with the evalutions program in the case of amputations at other levels.

Considering the role of the human hand as a projection of the brain and with the desire to develop an optimal system of tests that could serve as a basis for the general evaluation not only of this but also of other prostheses, it was concluded that it is indispensable to assume three basic types of tests which in general involve the activity of the human hand.

The human hand activity in space is based on the capability of bringing the hand into a definite position in which it will accomplish the act of grasping. From this fact originated the need to form tests of positioning and grasping.

Since man, in his everyday life, encounters a great number of objects of different shapes, sizes, weights, and structures, and placed at various points in space, the need was established for introducing uniform abstract tests symbolizing realistic situations from the domain of everyday life activities. These tests have been named "abstract" since they are not connected directly to practical work or execution of a particular task. They serve to direct the amputee's concentrated attention to the grasping function and control of finger pressure to achieve the necessary grasping force. The capability of the amputee to clasp an object depends partially on the amount of the force, and partially on the structure itself, and the shape, size, and other characteristics of the terminal device.

In selecting the object we have confined ourselves to geometrical bodies in the shape of a cube, ball, prism, and cylinder of definite sizes and materials. This enables us to execute always the evaluation of the grasping function by the terminal device in a standard and objective way.

Although grasping is considered to be a primary function of the normal human hand as well as of the prosthetic one; the capability of placing the hand or its substitute in space correctly represents one of the key factors in using the prosthesis. A normal person is capable of acting on three planes. To evalute the functional capability of the hand at various heights and under different angles, positioning tests with a series of common positions of the hand in action have been done. The application of positioning tests enables us to determine the level at which maximum efficiency in the operation is achieved with the terminal device, as well as the level at which functional shortcomings appear.

As the abstract tests represent only the symbols of particular activities and are not directly related to the practical needs of everyday life activities, a group of practical tests exhibiting the possibility of a complete recognition of functional evaluation has been formed. In addition to the abstract tests of positioning and grasping, these tests assume also the evalution of the amputee's capability to unite the mechanical operations of grasping and positioning in an optimal manner when executing some practical work.

Since this has been the first functional evaluation of the Belgrade electronic hand, we have confined ourselves only to unilateral amputations when selecting patients. To bring the patient into a realistic situation that compels the engagement of the prosthetic hand, it was imperative to select primarily those tests that involve bimanual work, since experience has indicated that patients tend to use predominantly the remaining extremity giving it a dominant role.

The next two criteria concern activities of particular interest to the amputee as well as the frequency with which he executes them. Not pretending to an absolute objectivity, a list of 20 everyday activities from the field of nourishment, dressing, and other needs has been established. Here, the patient has been given the opportunity to select freely ten activities which he considers most important and executes most frequently.

The evalution has been done according to a scale established in advance. The amputee should execute the operations as naturally as possible with as little compensating movements as possible. The aesthetic value has been evaluated with respect to the ease, gracefulness, and harmony of movements while efficiency has been reflected in the security, accuracy and speed of executing a certain task in which time is measured. Essentially the time is not important but it becomes a factor when related to accuracy and general way of design.

In addition to the unilateral amputations of the upper extremities at the below- and above-elbow level and disarticulation at the shoulder joint, the conditions for selecting patients incorporated in the study-group were the active use of any kind of prosthetic devices for six months at least, sufficient intelligence, emotional stability, and readiness for cooperation.

Definite selection of persons has been done after detailed medical, prosthetic, and psychological examinations.

The conventional classic sockets with a double wall and a special hand joint that allowed for a simple and quick replacement of the prosthetic hands for comparison and testing have been used. The patients were subjected to training with each of the hand types separately until they reached the maximum functional level.

Phase I Results

The analysis of the data obtained shows certain advantages of the Belgrade electronic hand with respect to the number and variety of jobs that it can do, security in grasping, capability of adjusting squeeze, as well as in the sense of voluntary control both of the opening and closing.

The patients with forearm amputations carried out their activities harmoniously and smoothly, and the extent of the operational capability of the terminal device was significantly higher than that with the upper arm (above-elbow) amputations where the patient had to pay particular attention to the constant control of the functioning of the prosthetic elbow.

However, a disadvantage so far has been the application of additional suspension created by the potentiometer type of control. The somewhat greater weight of the electronic prosthesis as well as of the associated equipment must be revised in further technological improvement.

To show the results of the clinical evaluation more clearly, we shall describe the sequence of the work done.

First, the cases of below-elbow amputations were considered. In the first phase of evaluation the potentiometer was used as the transducer through a suspension of the figure-eight type. The activation was by means of scapular excursion whose amplitude was reflected proportionately through the electronic logic to effect the terminal device. Its maximum value amounted to two cm.

Structural limitations in the application of the Belgrade electronic hand were encountered with below-elbow amputations at the level of the lower one-third as well as with disarticulations at the wrist joint. These limitations were solved by applying a flexible shaft.

After a six-week period of equipping and training, the patients were ready to execute the planned tests. Tests results were evaluated by a team of three persons according to the foreseen conditions and the results were recorded in the patients' dossiers.

Considering the results of the patients with below-elbow amputations obtained by comparing the executions done with the mechanical hand prostheses and the Belgrade electronic hand with potentiometer control, the following data were obtained:

1. The time needed for execution of the tests with the electronic hand was mainly intermediate between the time periods necessary to execute the tests with the mechanical hands. The Dorrance hand needed less time, and the APRL hand needed longer time with respect to the Belgrade electronic hand.

2. An advantage of the Belgrade electronic hand was the absence of systematic error of compression which was evident with the mechanical hands.

3. As far as the execution of the abstract tests was concerned, the somewhat worse results with the electronic hand were probably related to the fact that the tested patients were users of the mechanical terminal devices for a long time.

4. Location of the potentiometer through suspension in the figure-eight harness generally gave satisfactory results with the exception of the operation with the terminal device above the level of the mouth when it was impossible to activate the potentiometer,

as well as below the level of the knee where an involuntary and uncontrolled activation took place.

5. With the practical tests that comprised ten independently selected activities which the patient uses most frequently, the results were somewhat weaker in most cases. The time needed for execution was longer, and the number of errors greater. However, with the test of grasping the cylindrical objects that suggested the use of grasping by the fist, the Belgrade electronic hand has shown certain advantages reflected in better results and a shorter time of execution.

6. In addition to the mentioned objective data obtained by the evaluation, number of errors, and time measuring, the subjective opinions of the patients cannot be discounted. They have accepted the advantages of the electronic prosthesis and have expressed their wish to use it after the technological improvements based on the results of the evaluation are done and the serial production begins.

The initial difficulties encountered when trying to apply the potentiometer control with the patients having an above-elbow amputation called for a new approach to the problem of locating the potentiometer itself as a transducer transforming the travel of the shoulder belt into the control signal needed for regulating the prosthetic action. First, an attempt to build the potentiometer into the system of triple control was made but this caused confusion for the patients and did not give satisfactory results.

A compromise was made by placing the potentiometer into the assembly of the standard forearm part with activation through the Bowden cable that is usually used with mechanical prostheses for flexion of the forearm and operation of the terminal device. Thus, a hybrid system of the whole arm prosthesis was realized uniting the conveniences of the simple principle of mechanical control with the advantages of the electronic terminal device. At the same time the patient can retain the learned scheme generated through the operation with classic prosthetic means he uses every day, so that the time needed for training is considerably shortened.

It should be pointed out particularly, that the importance of the evaluation is not only to appraise simply the functionality but also to find simultaneously new solutions when prosthetically approaching the problems of the amputees. Since the equipping of the above-elbow amputees with the electronic hand was done successfully in this manner, standard testing was started after a training period.

A brief review of the results of testing gives the following conclusions:

1. The objective evaluation of above-elbow amputations based on the abstract tests of the Belgrade electronic hand in comparison with the mechanical hands was much more favorable than was the case with below-elbow amputations, that is, better scores, a shorter time period of execution and fewer errors were evident.

When handing the cylindrical objects made of wood (positioning test) the patients showed somewhat weaker results with a longer time period but in approximately the same inter-relation as in the previous tests.

2. The functional value of the Belgrade electronic hand was much more evident when considering the appraisal, time, and errors in executing the practical tests. Approximately 80 per cent of the practical tasks were done with better scores, shorter time periods, and without any errors with respect to the operation of the mechanical hands.

3. If we discount the troubles the patients had due to the weight and aesthetic appearance of the hand (as it has been presumed by the evaluation methodology) the subjective opinions of the patients are undoubtedly directed in favor of the electronic prosthesis.

The cases with shoulder disarticulation that were to have been covered according to the evaluation schedule were not processed due to the lack of components and suitable subjects.

Phase II Results

After the completion of the first phase, a second phase was started. In this phase the intention is to make the functional evaluation, whose basic parameters were obtained in the first phase, more complete.

The investigations in the second phase involve two aspects: parallel with the comparison of different modes of controlling the electronic hand, comparison of the latter with other externally powered electromechanical hands will be carried out.

In this phase some new transducers with a paint electrically sensitive to pressure will be applied. By means of these transducers control mode II has been generated comprising one transducer with the first variant of the logic quite analog to the potentiometer control named the control mode I. Also control mode III has been formed with two transducers and the second variant of the manipulation logic. It was foreseen that activation of the transducers by muscle contraction at a suitable place in the system would be such that the bulge of the control muscle would press the transducer and the signal magnitude would be proportionate to the pressure, i. e., to the extent of muscle contraction.

The first trial with control mode II caused adverse remarks on the part of the patients with regard to direction selection since, in this case, the motor operation direction changes successively at each activation of one control transducer. Therefore, the tests with control mode III were done where a particular transducer, i. e., two separate control sites exist for each direction. Since the Belgrade electronic hand, however, has two types of grasp in that the same motor direction opens the hand from the fist and closes it for grasping by the finger tips and vice versa, the result was that every control site can both close and open the hand dependent on the type of grasp. Therefore, the tests with control mode II were recommended with one control site only which the patients preferred.

In this way it was possible to activate the prosthesis by means of control signals generated by muscle contraction.

First, the below-elbow amputees were prepared. However, because of the weight of the prosthesis, as well as the weight of the grasped object, the transducer was dislodged from the control muscle because the prosthesis fell off. Then, in certain positions when the hand was brought to the mouth, it was not possible to obtain sure control. The hybrid control was again tried with surprisingly good results. The transducer was placed on the socket nearer to the hand and activated through a Bowden cable that was terminated by a special small adapter by means of which the pulling force was transformed into a pressure force. As a result the following advantages were noted:

The prosthesis socket no longer fell off.

The activation was quite sure at all levels and in all positions of the arm. Thus the disadvantage of the potentiometer control that failed for the hand positions above the mouth level and below the knee level was eliminated.

The training period was almost annulled since the patients have used the already well-practiced principle.

All the good properties of the electronic hand were retained,

Conclusion

Comparing the results of tests from Phase I with the results of tests by control mode II, it is evident that the scores are better, the execution time shorter, and number of errors less with the hybrid system of control through one transducer than with both the mechanical and electronic hands with potentiometer control. The same applies to the results of the practical tests.

The subjective opinion of the patients was very favorable since a standardization was achieved by the hybrid control that rejects the need for a tiresome identification of suitable muscles which can be completely useless with short amputations for signal generation.

Final results after the evaluation is completed will be used for the reconstruction of the Belgrade electronic hand; and the implementation of the serial production of the hand prostheses will be made possible for wide use.