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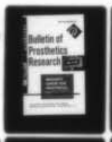

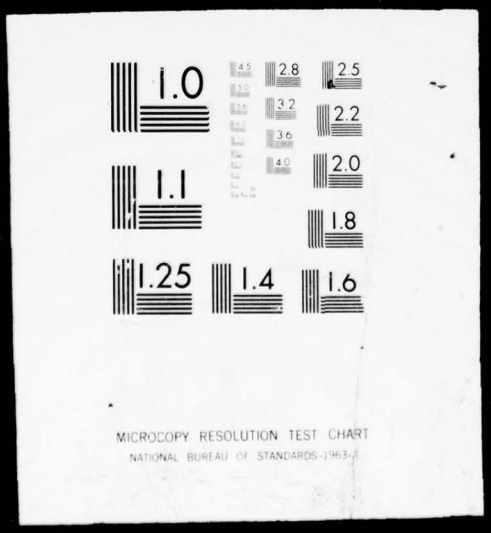

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RESEARCH CENTER FOR PROSTHETICS

DEPARTMENT OF MEDICINE AND SURGERY
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CONTENTS

ISPO – INTERNATIONAL KEY TO THE FUTURE IN AIDING THE HANDICAPPED

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. . . . an editorial

Here in New York in this Spring of 1977 the International Society for Prosthetics and Orthotics (ISPO) reached a new height in its professional stature. I was fortunate to be identified with this significant happening which took place in the last few days of May and the first few of June.

The Second Congress of the International Society (the first having been in Montreux, Switzerland, 1974) was supported by hundreds of contributors from all over the world. Unusual in its size was the response when last year our Scientific Program Chairman, Sidney Fishman, Ph. D., Director of New York University School of Prosthetics and Orthotics, invited submissions of papers. The result revealed an almost overwhelming interest in participation; the Committee which organized the Congress, and on which I served as President, was extremely encouraged after some earlier dim days when we had worried about how popular our event would be.

We built our program around a core of invited speakers, asking them to treat the current state of the art and perhaps some recent history of technical change in prosthetics and orthotics. Professor Charles W. Radcliffe, well known for his studies in prosthetics at the Biomechanics Laboratory at UC-Berkeley, presented the First Knud Jansen Lecture on Above-Knee Prosthetics. The submitted papers, which came from all over the world, were extraordinary in providing directions for the future, for delineating the status of prosthetics in selected geographical areas, and for discussions of problems and solutions associated with different types of patients.

[a]Member, Editorial Board, Bulletin of Prosthetics Research.

But this was not enough for the Congress Committee. From the very outset in our planning, we had felt that courses of instruction in specific areas of prosthetics and orthotics technologies would be needed to fully benefit the registrants; through these, explicit coverage of certain topics could be offered so that a participant could carry away with him or her something to be used *now* to benefit patients. With help particularly from A. Bennett Wilson of the Congress Committee as well as Dr. Fishman, we were able to organize an instructional course program the likes of which had never appeared before in any single event attended by professionals in prosthetics and orthotics. These instructional courses were extremely popular; the interest of Congress registrants was maintained during that whole week, and their comments were overwhelmingly positive (and some were ecstatic) about the Congress and particularly about the value of the courses.

But even this was not enough. We also offered symposia on various topics of special interest. In one we listened to the consumer, the user of prosthetic and orthotic services. There also was one in the very special area of orthopedic shoes, a subject usually bypassed by meetings devoted to prosthetics and orthotics.

But we wanted to offer even more by collecting an array of very good scientific and commercial exhibits. Both types were well received.

And still this was not all. Our video and film programs created a great deal of interest. These made additional instructional material available for the benefit of individual participants. Indeed, we were even able to give some private showings of special subjects, covered in our video library, that were of special interest to individuals.

But even all these educational efforts did not constitute our whole Congress package, for we were also able to organize a very excellent social program, which many people will long remember.

There were many aspects to this Congress, all of which needed coordination and management; we learned here about the advantages of professional management of such activities. We enjoyed the labors of such professionals, who eased our burden and made our Congress as successful as it was.

Over 1,000 registrants from about 40 countries participated; we were particularly pleased to see our colleagues from Eastern Europe and the Soviet Union in attendance.

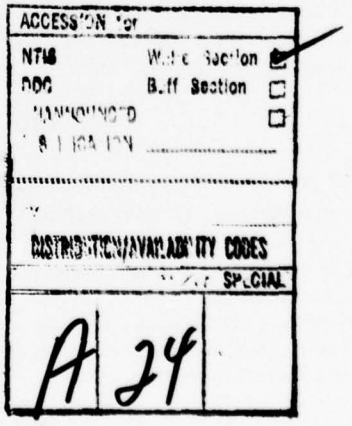
We also took this Congress a bit beyond prosthetics and orthotics, as the terms are often understood, into related areas of technical aids, mobility systems, and vehicles for the handicapped. In this process we were able to provide forums for these technical areas which are so closely related to the scope of ISPO. The Congress

constituted an arena for ISPO to relate its interest to the correlated interests of the International Commission on Technical Aids of Rehabilitation International. We were able, through these contacts, to recognize that we are not infringing on technical territories, but working together to facilitate the life of the handicapped.

These, and the other business meetings which took place within and around the Congress, signaled that ISPO is now able to move forward assuming its natural role as the key international society in the field of aids for the handicapped, especially prosthetics and orthotics.

We who organized this Congress feel strongly that the lesson learned here in New York, about the advantages of instructional courses in such a convention of professionals, is of great practical value to those who plan national and international meetings of similar kinds. The positive reactions we received were overwhelming on this point.

We now note with satisfaction that the 1980 Congress will be held in Holland. Our new president is the distinguished Dr. George Murdoch of Scotland who succeeds Dr. Knud Jansen. To our Dutch colleagues we not only express well wishes in their planning, but we offer all the help we can in their efforts to organize a successful meeting.



A MULTIFUNCTIONAL PROSTHESIS CONTROL SYSTEM BASED ON TIME SERIES IDENTIFICATION OF EMG SIGNALS USING MICROPROCESSORS[a,b]

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ABSTRACT

This paper describes a real-time system for separation among several limb functions, in order to provide multifunctional control of an upper-limb prosthesis for above-elbow amputees. The system employs microprocessor hardware and is based on identification of voluntary myoelectric signals resulting from isometric contractions of the musculature of the residual limb, and on subsequent discrimination of these signals for control of the several degrees of motion of the prosthesis. The system requires only one to two electrode sites. (Contrary to the usual placement of electrode pairs directly over specific muscle bellies, to eliminate crosstalk, we prefer to place our electrode pair *between* muscles so as to acquire the different weakly-correlated signals associated with each of several different voluntary functions.) The system satisfies the various practical constraints of weight, volume, and speed, as arise in practical prostheses. Preliminary amputee tests on the system have resulted in an 85 percent success rate using 8-bit double-precision microcomputer hardware.

INTRODUCTION

The problem of multifunctional control of upper-limb prostheses using myoelectric (EMG) signals is of major importance in cases of short above-elbow amputees. To solve this problem it is essential to be able to distinguish accurately each of the different signals, used

[a]This article is based on a paper presented at the International Conference on Cybernetics and Society, Nov. 4, 1976, held in Washington, D.C., sponsored by IEEE Group on Systems, Man and Cybernetics.

[b]Based on work performed under VA Contract No. V101(134)P-338

to control the respective artificial limb functions, from the pattern of the myoelectric signal at some or several locations on the residual limb. Therefore, differences in the pattern of myoelectric signals related to various limb functions (i.e., elbow flexion, elbow extension, wrist pronation, wrist supination, prehension, etc.), as taken from one or several residual limb muscles, must be detected. Although such differences do exist, they are hardly obvious to the naked eye of even an expert.

Two major approaches to solving this problem have been suggested.

One, based on the works of Lawrence (1) and of Lyman et al. (2), requires mapping of many (10 or more) electrode locations, at each of which the myoelectric signal is strongly correlated with a single prosthesis function. This method employs the low frequency characteristics of the myoelectric signals and of their distribution over the various electrode locations.

The other approach, developed by Graupe et al. (3, 4), requires a far smaller number of electrode locations (one to three) because it permits identification and discrimination even where correlations between the measured signal and the prosthesis control functions are very weak. This method is concerned with the complete spectrum since it considers the complete linear information content of the myoelectric signal (i.e., at all frequencies). It takes advantage of the "cross-talk" between signals due to different limb functions, rather than (as is usually the case) trying to filter out that cross-talk. It is thus more efficient in terms of utilizing the information content of the myoelectric signal and therefore fewer electrode locations are necessary, though at a price of requiring finer detection. We note that the above correlation with more than one prosthesis control function is due to the spatial integration effect of muscle fiber and skin tissue, which affects the signal as measured by surface electrodes (5) with placement of the electrode site between muscles.

The present paper will concentrate on the latter approach and describe a fast function separation and recognition algorithm, and the microcomputer hardware involved, as developed by the authors at Colorado State University. The speed, (recognition within about 0.2 s), weight, volume, and cost constraints for practical prosthesis application are noted.

OUTLINE OF THE FUNCTION-SEPARATION ALGORITHM

The principles of the present function-separation algorithm are based on time series model identification as in (3), though differ-

ing in the discrimination approach and in the identification subroutine used, as follows:

A. Parameter Identification

Because our approach attempts to extract the complete linear information content of the myoelectric signal, it is essential that data reduction be employed to the greatest degree possible in order to reduce the dimensionality of the problem without losing any information. This is achieved by first employing signal identification. Noting that the recorded myoelectric signal may be regarded as a time series that is essentially stochastic, our algorithm consists of identifying the parameters of this recorded time series in terms of an autoregressive (AR) model, given by the equation:

$$y_k = \sum_{i=1}^{n} \gamma_i \, y_{k-i} + \omega_k \qquad [1]$$

where y_k denotes the recorded signal, γ_i the AR parameters, n is the order of the AR model, and ω_k is white noise.

The use of an AR model in this problem is justified for the following reasons:

1. It can be proved that stationary time series can be represented by an AR model (6) as in Equation [1]. Although the myoelectric signal is not fully stationary, it has been shown (3) that this signal is sufficiently stationary, per each prosthesis control function considered, to result in AR parameters whose range of variation with time is sufficiently small to facilitate discrimination for multifunction prosthesis control.

2. It can be shown (6) that the minimum parameter linear model of a stationary time series is of the form of an autoregressive moving average (ARMA) model given by:

$$\sum_{i=o}^{m} \phi_i \, y_{k-i} = \sum_{j=o}^{p} \theta_j \, \omega_{k-j} \; ; \; \phi_o = \theta_o = 1 \qquad [2]$$

where y_{k-i}, ω_{k-j} are as in equation [1], ϕ_i and θ_j denote the AR and the moving-average (MA) parameters of the model respectively, and m and p are the order of the AR and of the MA parts of the model respectively.

Now, via polynomial division (6), equation [2] can be reduced to the form of equation [1], though it is not of minimum order. As may be seen in reference (6, section 12.6) the derivation of the minimum order ARMA parameters is rather lengthy and complex, especially compared with derivation of the AR parameters for a low order AR model. Since, in our case, computational speed is of

utmost importance and since it has been shown (3) that for myoelectric signals for upper-limb prosthesis control, n = 3 or 4 is adequate for functional discrimination and for obtaining ω_k that is almost completely white (uncorrelated), we have gone back to using an AR rather than an ARMA model in our analysis and design.

3. The linear model, as in equation [1] or [2], is fully optimal only if y_k is Gaussian, and is otherwise only linear-optimal—i.e., the best linear model for y_k. Hence, in the non-Gaussian case, a nonlinear signal model would be required for full optimality. However, without prior knowledge of the parameters, which is not available in our problem, no identification of an optimal model is possible. It should be noted that even if such knowledge were possible, it would still be too lengthy and too complex from a computational point of view to satisfy the constraints (Section A) imposed for practical prosthesis application.

Furthermore, it has been reported (5) that myoelectric signals can be considered as an outcome of a sequence of impulses with independent Poisson distributed intervals passed through a linear filter. Now, since the muscles involved (biceps and/or triceps) are usually actuated by a large number of motor units (7), say several hundred, the average Poisson interval between impulses is small compared with the dominant time constant of the linear filter. Assuming the practical average interspike interval concerned is of the order of t=100 ms, and assuming that N=200 motor units are involved in the isometric muscle contraction, the respective Poisson rate is $\lambda=N/t=2000$. Such a Poisson rate implies (8) that the myoelectric signal thus closely fits a Gaussian process. This further helps establish the validity of the linear AR model and indicates it is close to an optimal one.

For the above reasons, and noting the speed, weight, and volume constraints imposed by upper-limb prosthesis application, the choice of an AR model is thought to be well-founded.

The algorithm used for identifying the AR model above is a sequential least squares algorithm (Sections 5 and 12.6 of reference 6). This algorithm can be proved to converge to the true parameters of the signal (6, 9). Furthermore, its near-maximum-likelihood properties make it a near-efficient algorithm and therefore of fastest possible convergence rate (10); that is, it requires the least number of samples for convergence. This aspect is important in view of the constraint imposed on computational speed. But the basic least squares algorithm (6) requires a large number of computations per sample, which makes inter-sample computation time lengthy. We therefore presently employ an accelerated version of this algorithm (11), which preserves the property of fast convergence in terms of

number of samples but requires fewer computations per sample, thus reducing the overall identification time and the amount of hardware needed.

B. Limb-Function Discrimination

The identification procedure (Section A) is employed in the prosthesis control system by being run several times (say L times) per each limb function, for calibration purposes. The parameters obtained during these identification runs are averaged over the above runs and stored as sets

$$\{\bar{\gamma}_{11} \cdots \bar{\gamma}_{1n}\} \; ; \; \{\bar{\gamma}_{21} \cdots \bar{\gamma}_{2n}\} \; , \cdots \; \{\gamma_{h1} \cdots \gamma_{hn}\}$$

when h different limb functions are considered, each having n parameters. Once these parameters are stored, another calibration run[c] is made where the EMG signals $y_{k,\,i}$ (k = 1 . . . N, denoting time interval) related to function i (i=1 . . . h) are fed to an algorithm (i.e., a filter) that computes:

$$\hat{y}_{ki} = \bar{\gamma}_{i1}\, y_{k-1} + \bar{\gamma}_{i2}\, y_{k-2} + \cdots \bar{\gamma}_{in}\, y_{k-n} \; ; i = 1, \ldots h \quad [3]$$

(Alternatively, one may compute $\hat{y}_k$ from the ARMA model of equation [2], to obtain

$$y_k - \hat{y}_{ki} = e_{ki} \quad [4]$$

where y_k = the actual myoelectric signal at the k-th time interval.

Defining:

$$E_i \triangleq \frac{1}{N} \sum_{k=n}^{N+n} e_{ki}^2 \; ; \; i = 1, \ldots h \quad [5]$$

and averaging over L runs now yields $E_1 \ldots E_h$ for limb functions 1 to h, which are stored in the memory of the microcomputer.

The microcomputer system now performs the limb function discrimination as follows: feed the measured myoelectric signal y_k in parallel to filters (ARMA models) 1 . . . h to compute e_{k1} to e_{kh} as in equations [3] and [4]. From the above, compute E_i

[c]Total calibration time is 2-3 minutes. Calibration is performed by a microcomputer system based on the same microprocessor hardware used throughout. The calibration mode is actuated by a single "mode" switch to be turned by the amputee.

i = 1, . . . h, and compare

$$E_i = \min_j E_j \text{ with } \bar{E}_i \text{ above.}$$

Finally, if:

$$E_i \leqslant \rho_i \bar{E}_i \quad ; \quad \text{where } \rho = \text{weighting coeff.} \qquad [6]$$

and

$$\sum_{k=1}^{M} y_k^2 \geqslant A \qquad [7]$$

to prevent actuation for a low E_i due to a situation where no myoelectric signal is measured, then limb function i of the set of limb functions 1 . . . h is actuated. If this is not the case, the prosthesis will be (or remain) in a "hold" mode.

The above procedure, equations [6], [7] and the use of $\rho_i \neq 1$ serves to overcome the not completely stationary nature of the myoelectric signals related to a specific prosthesis function.

In diagrammatic form, the present design is illustrated in Figure 1. For increasing speed, hardware multipliers are used in the hardware realization of the system shown in Figure 1, especially in the blocks of the lower half of the diagram.

Note that the present design involves only simple filtering, namely multiplication and addition, rather than identification, during normal prosthesis use, whereas identification is solely performed during calibration: since identification is the most time-consuming part of the system, this implies a considerable time saving. However, discrimination may be somewhat sensitive in certain situations via this approach; i.e., when the parameters employed are somewhat biased due to incomplete convergence or to inadequate model order. Therefore, if an identification bias exists, the method of comparing parameters in a parameter vector space may be advantageous (3). (In the discrimination approach (3), discrimination must be exact if $\bar{Y} = \hat{Y}$, whereas in the present method this is not necessarily so, since the minimal error-variance may occur for the wrong prosthesis control function due to identification bias.) However, since in the present design identification is performed only during calibration and not during normal operations, sufficient computation time should be available to obtain convergence so that any biases can be eliminated.

Furthermore, if access to calibration computers is adequate, the whole calibration (top half of Figure 1) can be done by a calibration computer in a clinic so that the related hardware will not have to be incorporated in the prosthesis and be worn by the patient,

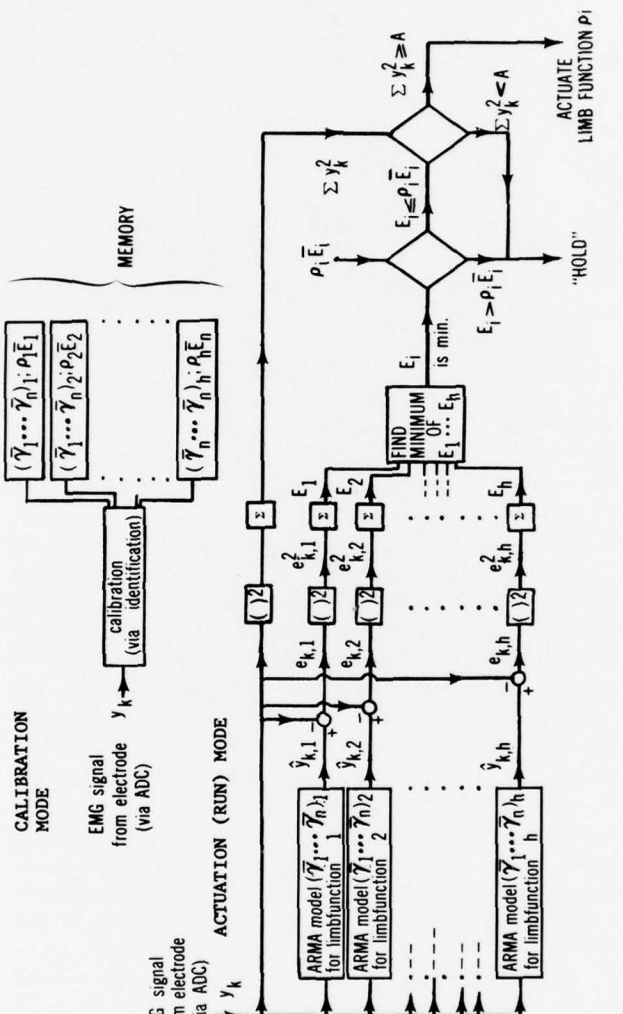

FIGURE 1.—Function discrimination scheme. The upper portion of the figure represents the Calibration Mode in which identification is performed: the larger, lower portion of the figure represents the Actuation Mode employed during normal prosthesis use. In an alternate arrangement described, the whole calibration top portion of this figure could be performed by a calibration computer in a clinic.

thus further reducing weight and cost. This, however, requires facilities for re-programing the AR parameters (top portion of Figure 1), namely $\{\bar{\gamma}_1 \ldots \bar{\gamma}_n\}$ and $\bar{E}_i$ for i=1 . . . h in the memory of the patient-worn microprocessor system as computed by the calibration computer in the clinic.

C. Control Aspects

Our present design (using only one electrode pair) can identify and discriminate five functions (j=1,2,3,4,5 above); prehension may be controlled by toe-actuation (4). Furthermore, toe movement may be used to interrupt prosthesis movement if discrimination turns out to be wrong, or to facilitate speed control. This design thus also facilitates speed and torque control.

A design for all seven of these functions is also ready; however, it involves two parallel microprocessor systems, the hardware for which is not yet complete. (A single very fast microprocessor, where computation of the tasks of the two parallel systems may be done in series, might also be used.) We note that the present five-function system employs only a single set of electrodes in contrast to two sets for the seven-function system.

DESCRIPTION OF HARDWARE

We have indicated in Section C that the present system involves one set of electrodes for discriminating and controlling five limb functions. The system feeds to a motor control and actuation unit identical to that used in a toe-controlled system (4) which has been tested by a bilateral above-elbow amputee in Los Angeles, California.

A block diagram of the system is shown in Figure 2.

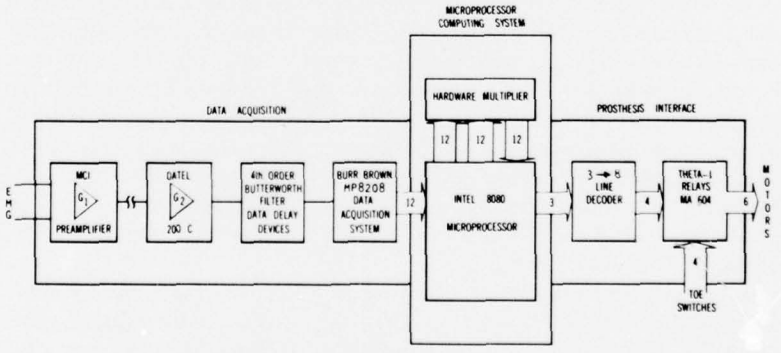

FIGURE 2.—Block diagram of system.

A. Data Acquisition

The myoelectric signal is picked-up via an EMG preamplifier unit manufactured by Motion Control Inc. (MCI), Salt Lake City, Utah. Disk type electrodes are mounted directly on the preamplifier module. (As noted above, the electrode-preamplifier assembly is located between muscles; e.g., on the medial aspect of the humerus between biceps and triceps.) The preamplifier weighs only 8 grams and does not require the use of conductive jelly or electrode paste which is often used and which can be a source of inconvenience and unreliability.

The preamplified myoelectric signal is fed to a Datel 200C instrumentation amplifier for further amplification. Undesirable frequencies are filtered out by a 4th order Butterworth bandpass filter (with a passband between 1.5 and 1500 Hz) produced by Data Delay Services. A 12-bit data acquisition system (the MP8208 produced by the Burr Brown Research Corp.) samples the EMG signal at a rate of 5000 samples per second and delivers the digital data to the microprocessor computing system. (See Figure 2 for details.)

B. Microprocessor Computing System

The microcomputer system is based on an Intel 8080 microprocessor which is an 8-bit parallel central processing unit (13). It is fabricated on a single LSI (large scale integration) chip using the latest advances in N-channel silicon gates and is furnished in a 40-pin dual in-line ceramic package, having a 2 μs instruction time (for instructions that do not refer to memory). The microprocessor is then interfaced with its input-output ports and with 4K-bytes of semiconductor memory. Furthermore, to increase speed, and since the multiply and divide instructions are the most time-consuming ones in our program, the microprocessor is also interfaced with a hardware multiplier unit based on Fairchild 9344 4X2 bit multiplier modules where multiplication time is 350 ns as compared with 1 ms in the microprocessor itself. (Note that since no division is made during normal operation, hardware division is not presently performed.) Via the latter arrangement, the complete recognition is performed within 0.2 s for the five-function system, which is within the desired time limit.

It should be noted that even with the hardware available today, such as the Intel 3000 system (which was not available when equipment for this project was purchased), a 10-times-faster system can be achieved using the same algorithm. Observing that 12-bit data

are used, the 8-bit 8080 program must be written using double word length. Therefore, use of a 16-bit microprocessor such as those now becoming available (i.e., the Plessey MIPROC-8) would further increase the accuracy and speed of the system.

C. Prosthesis Interface

The interface between the microcomputer system and the prosthesis is basically identical to that of the toe-controlled prosthesis (4). We note that the system may also incorporate toe control for interrupt, speed control, and grasp. The latter functions may alternatively be performed via processing EMG data from two electrode locations, using either two microprocessors in parallel or one fast microprocessor operating in a multiplex mode.

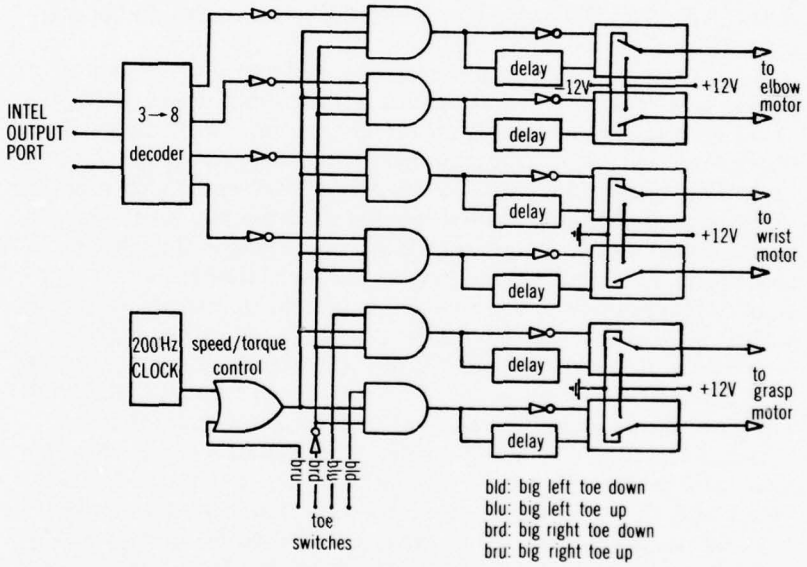

FIGURE 3.—Prosthesis interface schematic.

The microprocessor computing system latches the binary function code into an output port, from where it is decoded by a 3-to-8-line TTL decoder. The signals from the decoder directly control DIP solid-state DC power relays (MA-604 manufactured by Theta-J Relays, Inc.) which switch the power to the prosthesis' motors (Fig. 3).

FUNCTION DISCRIMINATION PERFORMANCE

The first tests using this microprocessor-based system were performed with data taken from an above-elbow amputee (amputated 7 years earlier) who had no prior training. He had severe neural and muscle loss (he had virtually no triceps, and had lost more than 2/3 of his biceps). Further tests with this amputee have yielded a success rate of 85 percent to 95 percent for discrimination among five limb functions (elbow flexion and extension, wrist pronation and supination, hold), using 3rd order AR reference models based on 200 data points and where the least squares algorithm (6) was used. Discrimination was complete within 0.2 s, using double-precision algorithms on the 8-bit Intel 8080 system described previously. With training of the amputee, and using a higher-order AR model and a longer data sequence for improved convergence (see Section B), considerable improvement in accuracy is anticipated.

In contrast to the system described in reference (3), the present system is very sensitive to identification bias since discrimination is based on a scalar error function rather than on a high dimensional vector, the scalar error function being minimal only in the bias-free case. Hence, since the unbiased AR model involves a higher number of parameters (infinity, in theory) that decrease exponentially (6), a 3rd order model is certainly biased. The use of the 3rd order model was, however, necessitated by our speed limitations. To overcome this limitation, and to reduce bias (i.e., to increase accuracy) we have recently replaced the least squares algorithm (6) with a faster version based on Luenberger's optimization by vector space methods (11), to obtain a four-fold increase in computation speed. This now allows identification of six parameters within 0.2 s.

Initial amputee tests using this faster algorithm show an enhancement of 5 percent in accuracy when four parameters are identified, versus the three-parameter case. We also comment that we have recently acquired a 16-bit Plessey MIPROC-8 microprocessor system, which is 10 times faster than our present Intel system. Once the algorithms and the analog interface are modified for this new system, present speed problems should be fully overcome—even using the original least squares algorithm which is more accurate than the speeded up version (11) for any number of parameters, due to its better convergence (10). Furthermore, using the MIPROC-8 system at double-precision should improve computational accuracy, due to reduced round-off errors, and thus contribute to even higher success rates. We also comment that since 16-bit microprocessors of equal or higher speed than the MIPROC-8 are now

commercially available, further increases in discrimination speed are a certainty.

CONCLUSIONS

We have described a prosthesis control system based on microprocessor hardware whereby control of an artificial limb for above-elbow amputees is accomplished in several degrees of freedom. (We comment that though this discussion relates to above-elbow amputees, a major beneficiary may be the shoulder-disarticulation amputee, for whom many functions must be activated yet only a few control sites are available.) The design is based on employing time series identification techniques for parameter discrimination. The system's design is outlined in terms of its hardware and software. The system is presently undergoing clinical testing on an above-elbow amputee in cooperation with the Prosthetic and Sensory Aids Service of the Veterans Administration Hospital in Denver, Colorado, and initial results are reported.

We comment that the present system enables multifunctional limb control at will, with minimal training, using one or two electrode sites, and is within volume and weight constraints for practical prosthesis applications. An incorporation of the present system with a toe-controlled one for increasing the number of controllable functions, as is required for bilateral above-elbow amputees, is also underway.

The clinical test results reported are for a Vietnam-era amputee who was amputated 7 years ago and who had no previous EMG training. These results were obtained after only several hours of work with the system, this time being in periods of 30-45 minutes work with the system, separated by 2-6 weeks with no additional training in-between. All our results are real-time obtained from standard microprocessor hardware as described, using 8-bit double-precision word length on an Intel 8080-based system.

ACKNOWLEDGMENTS

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THE I.N.A.I.L. EXPERIENCE FITTING UPPER-LIMB DYSMELIA PATIENTS WITH MYOELECTRIC CONTROL

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In the early 1960's, because of widespread use of thalidomide, a sedative taken by women in early pregnancy, a large number of children were born with severe congenital anomolies, notably dysmelia. These children, now approaching early adulthood, require the application of acceptable functional cosmetic prostheses to serve both their personal needs and to enable them to enter into the social and occupational environment of the community.

Until recent years, for the very severe forms of dysmelia, the only means of prosthetic treatment has been with pneumatically powered prostheses (Fig. 1). Regrettably, our surveys indicate that a very high percentage of children have rejected this type of upper-limb prosthesis. The parents may be a major factor in this rejection because, in performing the activities of daily living for these children, they have diminished the children's desire to help themselves and to be independent. Another reason often cited is the complexity of the prosthesis itself and the difficulty of securing fresh supplies of energy. Special equipment is required for refilling the gas cylinders (Fig. 2) and this restricts the distances wearers can travel from home unless they carry the necessary cumbersome equipment with them.

There are also limitations from the standpoint of function, limitations which do not actively permit all desired movements. (For example: at the elbow, flexion is active and extension is by gravity; at the wrist, supination is active while pronation is by a spring; and at the shoulder, flexion and extension are passive motions with a pneumatic lock.)

These disadvantages naturally diminish considerably the desirability of using pneumatic power for dysmelics.

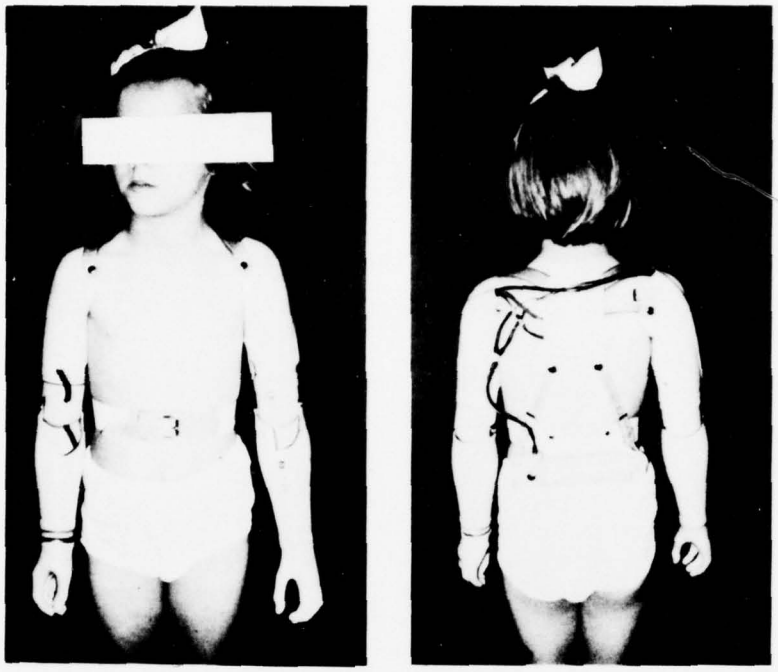


FIGURE 1.—Subject with bilateral upper-limb congenital malformations fitted with pneumatic prostheses.

Following development of reliable myoelectric prosthetic control components, we began fitting large numbers of bilateral upper-limb amputees, including patients with shoulder disarticulations, with electrically powered prostheses. Functional results were superior to those obtained with any other type of prosthesis.

These results became known, and our Rehabilitation Center at Budrio began receiving inquiries from people with severe congenital upper-limb malformations. This caused us to evaluate the feasibility of starting a program for dysmelics using myoelectrically (EMG) or electronically (switch) controlled prostheses.

This program was begun in 1972. Today it is possible to state that the system we developed, utilizing myoelectric control of the prostheses, gives greater satisfaction and provides the patient with better function than the pneumatically powered prostheses we previously used. This system has been applied to persons of different nationalities, having congenital amputations of various types, and with varying degrees of neuromuscular and intellectual ability.

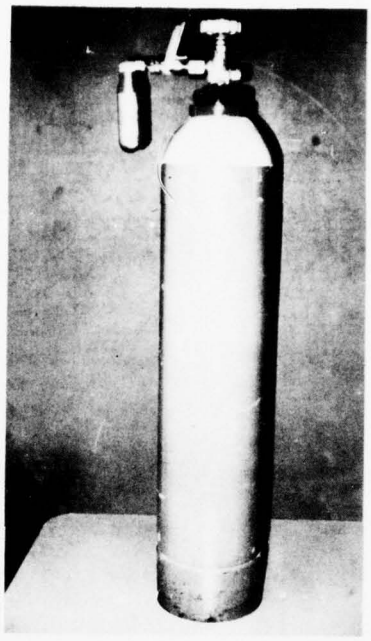


FIGURE 2.–Cylinder for recharging small CO_2 cylinders.

From our large patient population, it is possible to note some statistical trends. At first it was thought that electrically powered prostheses could not operate as naturally, or deveop as strong a prehension force, as pneumatic prostheses. This assumption has been shown to be incorrect. Table 1 lists comparisons between pneumatic and electrically powered systems and compares various technical specifications of the two systems with which our center has extensive experience.

From our studies, as evidenced in Table 1, the prostheses utilizing electrical energy have surpassed the pneumatic prostheses. Furthermore they have the additional advantage that, for recharging the power pack, no special containers are necessary; any standard electrical power outlet of 125 to 220 V can be used. All that is needed is a battery charger about the size of a pack of cigarettes. A disabled person is no longer restricted but can move about freely and confidently; he can travel without having to carry large CO_2 gas supply cylinders and other specialized equipment with him.

TABLE 1.—*Pneumatic vs. Electric Prosthesis Power: Some Technical Specifications Compared*

Technical specifications		
	Otto Bock pneumatic hand system	Otto Bock electrical hand system
System pressure or voltage	5 atm (506 kPa)	12 V
Maximum opening	65 mm	100 mm
Maximum prehension force	7 kPa	15 kPa
Speed of movement	45 mm/s	80 mm/s
Total weight	340 g	450 g
Average number of grip movements per charge of power pack (48 g (5 bar) of CO_2; 450 mAh battery charge).[a]	1300	4200
	Otto Bock pneumatic wrist rotation unit	Otto Bock electrical wrist rotation unit
System pressure or voltage	5 atm (506 kPa)	12 V
Maximum range of rotation	190 deg	360 deg
Maximum torque	7.5 cm-kPa	10 cm-kPa
Weight	140 g	120 g
Average number of rotation movements per charge of power pack (48 g (5 atm) of CO_2; 450 mAh battery charge).	1050	1350
	Otto Bock pneumatic elbow unit	Otto Bock I.N.A.I.L electrical elbow unit
System pressure or voltage	5 atm (506 kPa)	12 V
Range of motion (flexion)	0-130 deg	0-130 deg
Speed of flexion	3 s	1.8 s
Speed of extension	3.5 s	2 s
Weight	320 g	410 g
Average number of flexion-extension movements (full range of motion) per charge of power pack (48 g (5 atm) of CO_2; 450 mAh battery charge).	420	750
	Otto Bock CO_2 power pack	Otto Bock 12 V rechargeable nickel-cadmium battery
System capacity	48 g (5 atm) CO_2	450 mAh
Weight	350 g	280 g
Dimensions	36 X 140 mm	16 X 58 X 150 mm

[a]Definition of average grip movement: an average grip movement as here defined begins with the hand opened to 50 mm. The hand is closed 30 mm to grasp an object 20 mm thick with a force of 3 kPa. It then releases its grip and opens 30 mm to the original starting position of 50 mm opening to begin a new grip movement.

RESIDUAL LIMB FUNCTION AS A CRITICAL FACTOR IN THE DESIGN OF A PROSTHESIS AND ITS CONTROL SYSTEM

Special care must be given to the evaluation of the function and efficiency of the residual limb, and how it may be utilized and incorporated in the prosthetic system. A fundamental concept which must always be borne in mind is that the control mechanism of the prosthesis must be located on the same side as the amputation. This factor is of the greatest importance in the case of bilateral involvement because it is a necessary condition for the achievement of independent control of the two prostheses.

Once an evaluation has been made of the degree of function of the residual limb which may be utilized, it is necessary to decide whether the remaining prosthetic function can be controlled with a single myoelectric controller or if it is necessary to use additional controls (such as microswitches, transducers, or mechanical devices).

Because, in cases of congenital malformation, the myoelectric potentials required for prosthesis control are not always available, we have developed a fitting protocol. Our protocol successfully involves utilization of the following components, singly or in various combinations, as the severity and level of involvement increase:

1. A myoelectric amplifier for control of a single function from each muscle (Fig. 3). (Note the size as compared with the U.S. one-dollar coin.)

2. A multi-channel myoelectric amplifier and electrodes for control of two functions using signals from one muscle (Fig. 4). This is achieved by using a minimal to sub-maximal signal to proportionally control movement of a prosthetic component in one direction. (For example: hand closing, wrist supination, or elbow flexion might be controlled by a myoelectric signal whose amplitude is between 20 and 60 μV.) A maximal contraction (exceeding the previous upper threshold) is used to control movement of the prosthesis in the opposite direction at a fixed rate (for example: hand opening, wrist pronation, or elbow extension might be controlled at that same electrode site by a myoelectric signal whose amplitude is between 60 and 100 μV.).

3. Specially constructed myoelectric amplifiers which respond solely to special levels of muscle potential that a given patient is capable of generating (Fig. 5).

4. Electrical control (Fig. 6) by means of—
   a. Pressure-operated microswitches, which for example may

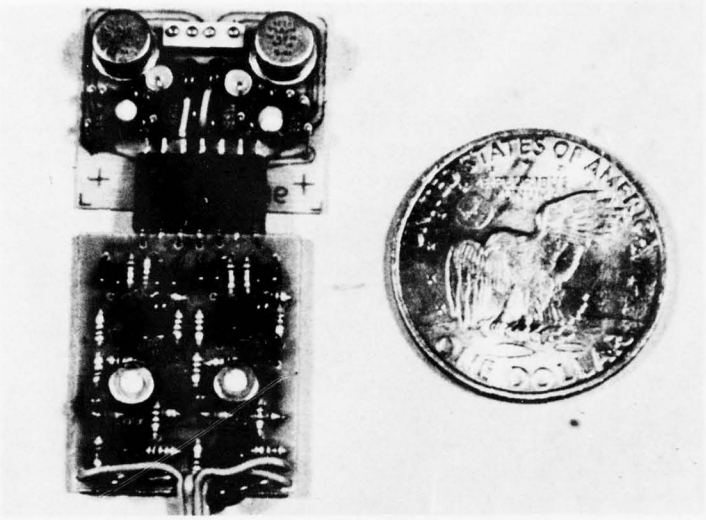


FIGURE 3.—Single-channel myoelectric amplifier. The illustration shows the items at approximately their actual size.

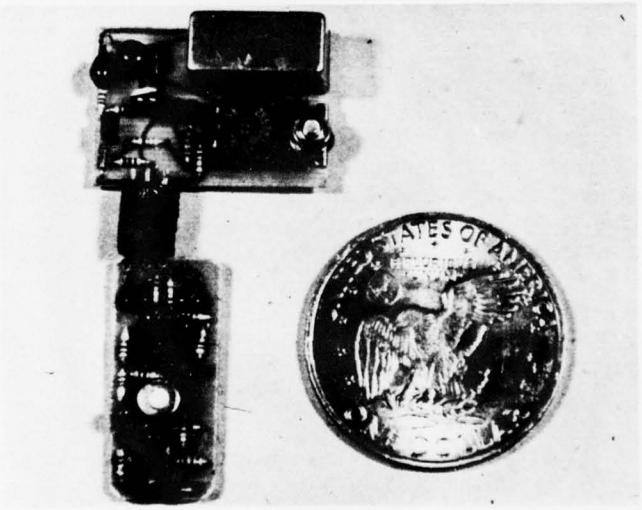


FIGURE 4.—Multichannel myoelectric amplifier with small scale integrated circuit (SSI) elements. The illustration shows the items at approximately their actual size.

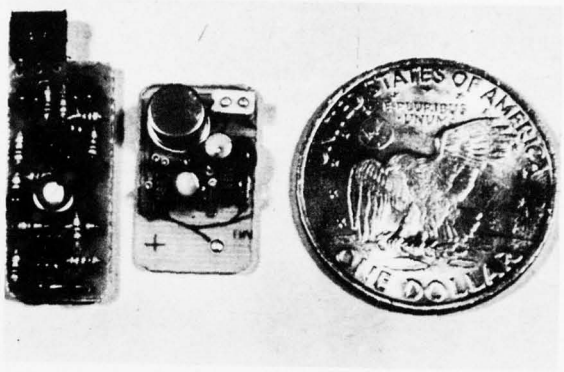


FIGURE 5.–Amplifier made with special characteristics that respond solely to special levels of muscle potential. The illustration shows the items at approximately their actual size.

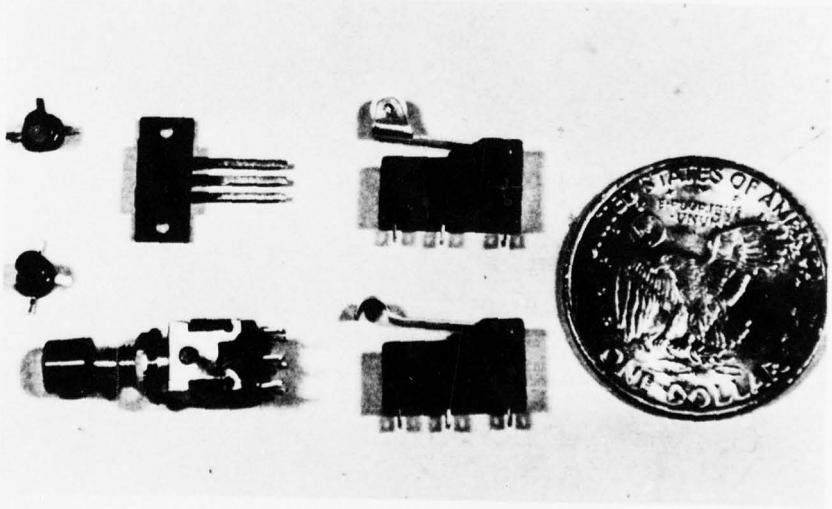


FIGURE 6.–Various microswitches and sensors (capacitance switches) for control of prostheses. The illustration shows the items at approximately their actual size.

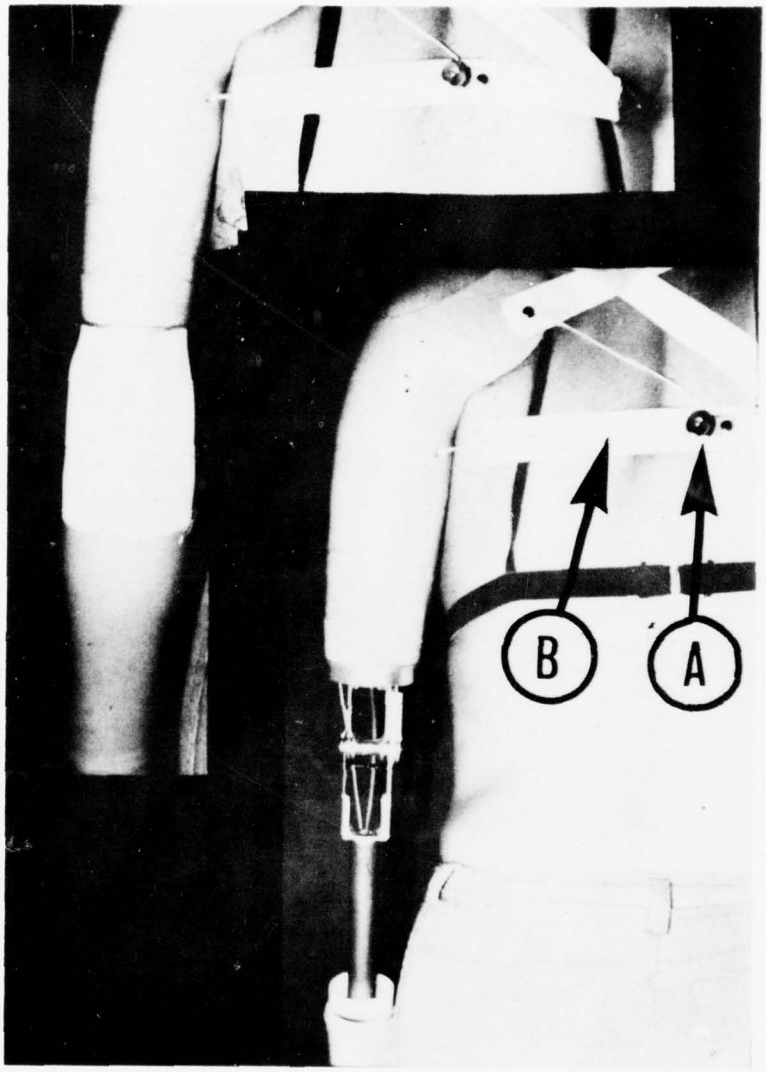


FIGURE 7.—Mechanism for control of a kinematic (body-powered) elbow joint. Arrows indicate pulley (A) and control cable (B). Another view of the same prosthesis, above and to the left, shows elbow and forearm with cosmetic covering in place.

FIGURE 8.—Patient with congenital bilateral amelia demonstrating a specially designed mechanism for simultaneous or individual control of elbow joints.

(Fig. 8 continues on pages 26 and 27.)

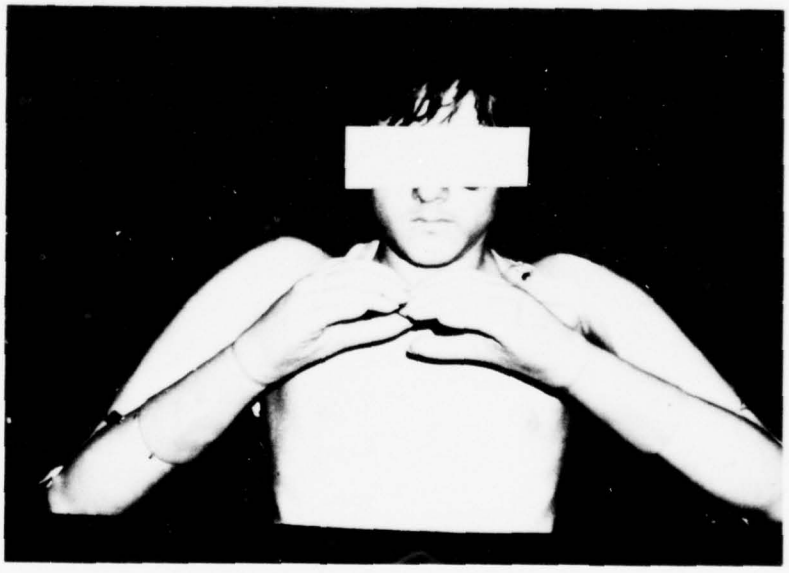
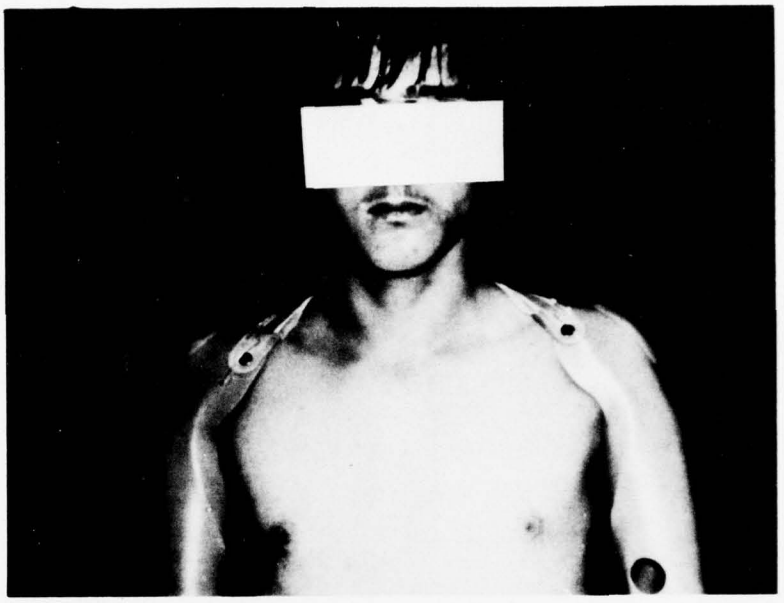
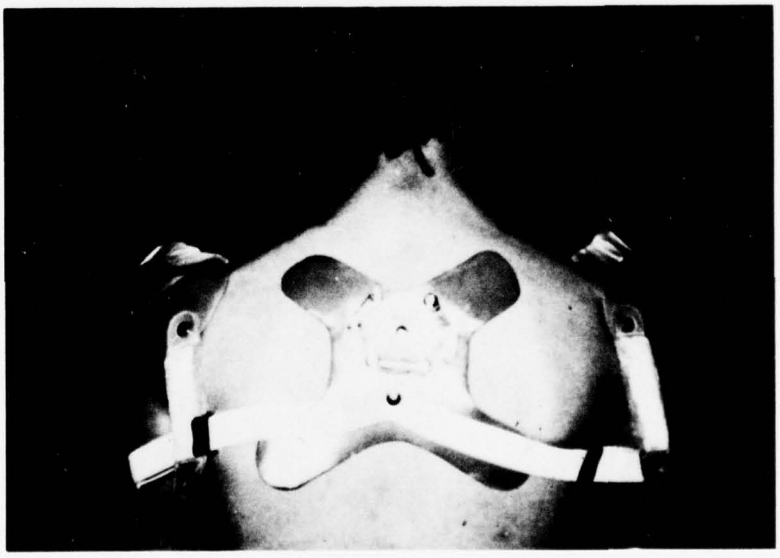
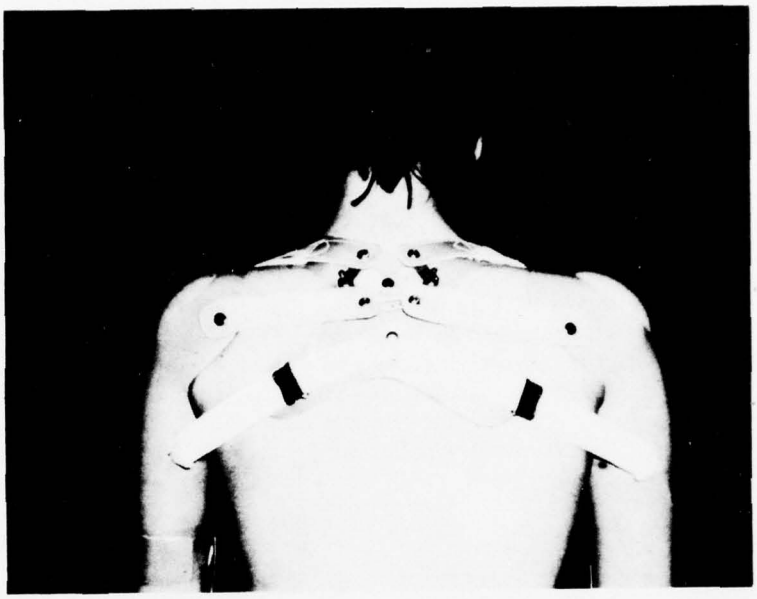


FIGURE 8 (continued).





Flexible back piece with control and suspension straps disconnected.



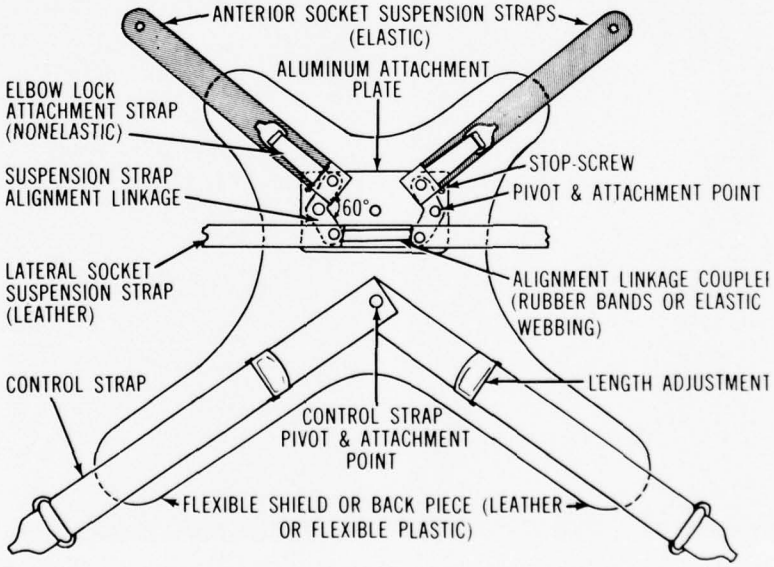


FIGURE 9.–Schematic of mechanism for simultaneous or individual control of elbow joints in cases of bilateral congenital malformations.

be operated by rudimentary fingers in phocomelias;

b. Traction-operated switches, which for example may be operated by scapular abduction, shoulder elevation, etc.; and

c. Sensors (capacitance switches).

5. A mechanical control for flexion-extension of the elbow with a multiplier system associated with elbow locking (Fig. 7). (This device includes a small pulley, around which the control cable travels, located on the chest strap portion of the harness. This mechanism serves two purposes: (i) to keep the angle of pull on the control cable such that it always falls across the distal 1/3 of the scapula, thus optimizing the amount of excursion obtainable from residual gleno humeral flexion and scapular abduction, and (ii) depending upon the diameter of the pulley used, it amplifies the amount of excursion obtainable from scapular abduction by an appropriate ratio.)

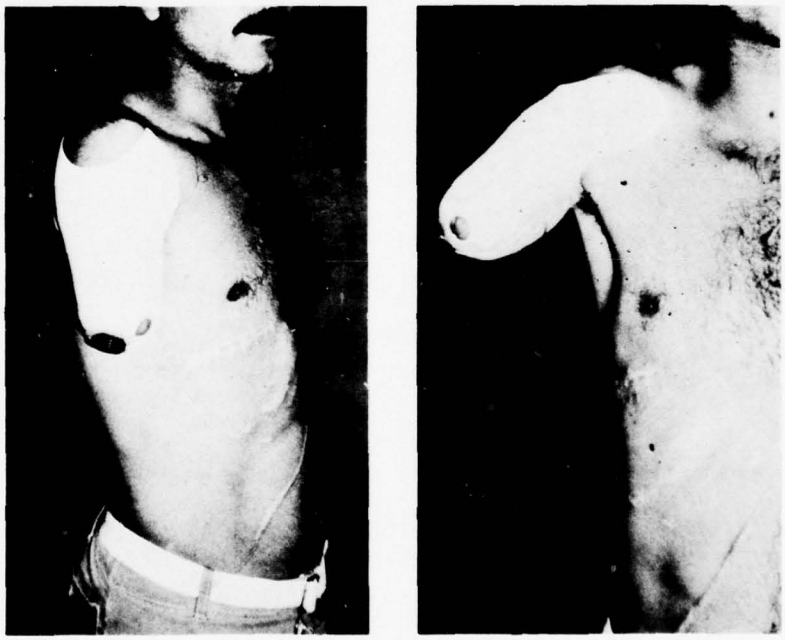


FIGURE 10.—Socket with partial shoulder cover and good freedom of movement in abduction.

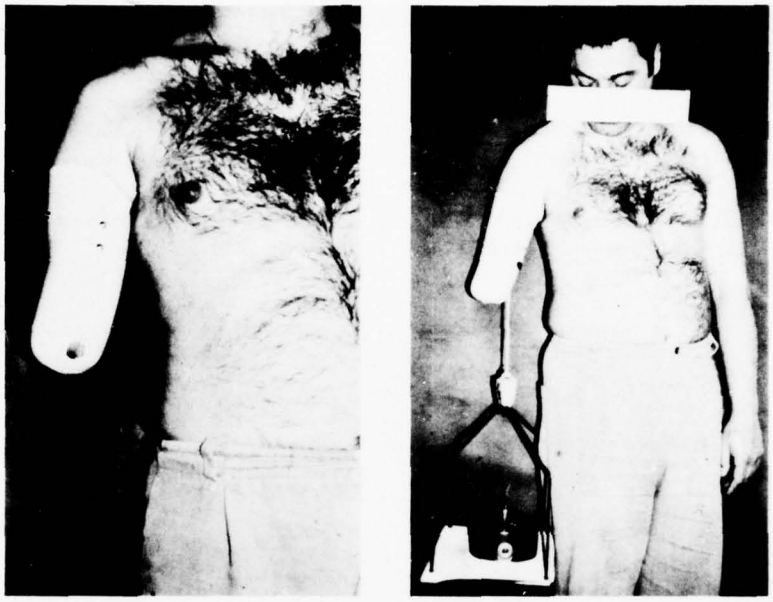


FIGURE 11.—Total contact socket; one can note the total contact even when loaded with a weight.

6. For bilateral above-elbow amputations, a mechanism has been designed where Hosmer locking elbow joints are used. This mechanism permits simultaneous or individual control of kinematic elbow joints and prostheses in cases of bilateral congenital malformations. It serves to always maintain optimal suspension of the prostheses and optimal alignment of the control strap and elbow lock attachment strap for each prosthesis irrespective of the position of the other prosthesis (Fig. 8 and 9).

The degree of function of the overall prosthetic system depends on two factors:

a. the maximum utilization of any remaining function of the residual limb and
b. the control of the single movements, such as control of terminal device grasp, or elbow flexion-extension.

In order to secure maximum utilization of the residual or malformed limb from the standpoint of functional capacity of the prostheses, and in order that the movements of the residual or the malformed limb shall control the movements of the prosthesis, it

is necessary that there be total contact between the prosthesis and the residual limb, or rather there must be created almost a single unit between the prosthesis and the residual limb itself (Fig. 10 and 11). For this purpose it is of the greatest importance that the socket be made with the utmost care especially in the case of malformations. The design of the socket cannot be standardized; in many cases special designs must be created which are suitable to the malformed limb. Only in this way is it possible to obtain the maximum range of motion or work envelope (Fig. 12).

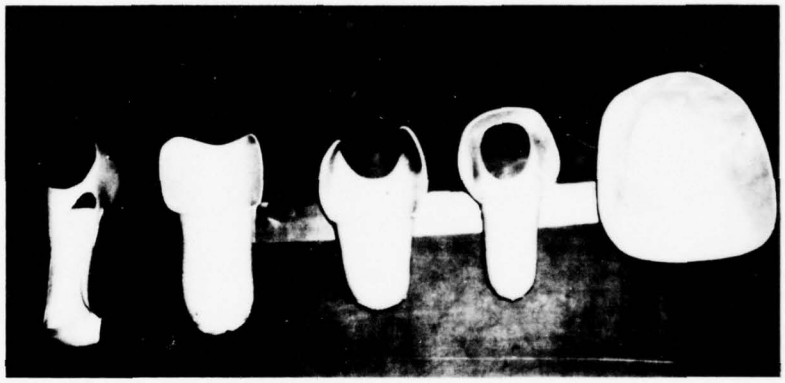


FIGURE 12.—Types of socket design illustrating the variety of designs required for particular prosthetic management.

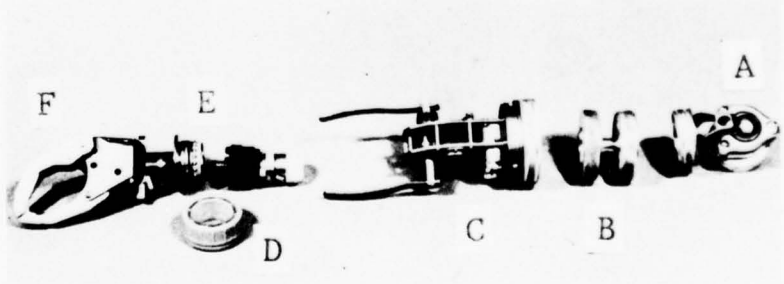


FIGURE 13.—A complete upper-limb prosthetic system and its component parts: a. passive-friction gleno-humeral joint; b. passive-friction adaptation (upper arm joint); c. I.N.A.I.L. elbow; d. quick-disconnect wrist unit; e. Otto Bock wrist rotation unit; and f. I.N.A.I.L. hand.

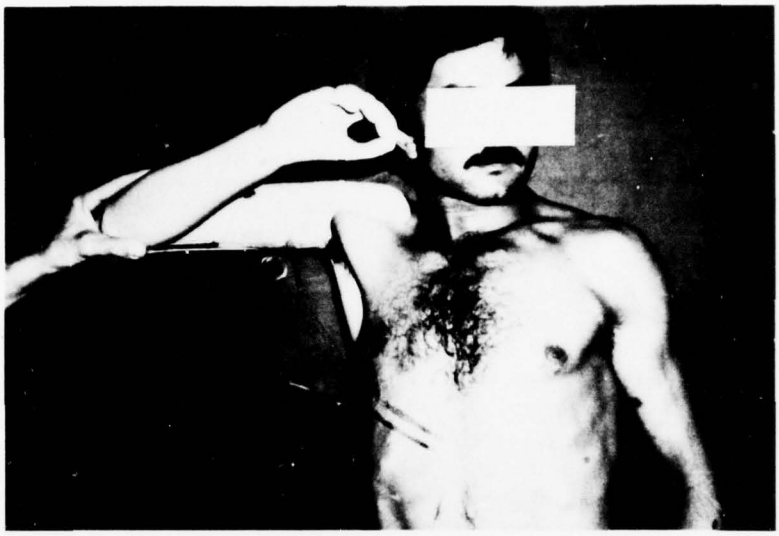


FIGURE 14.–The two illustrations above demonstrate the range of motion required of the assembled prosthesis to achieve the amount of mobility desired.

Once the socket has been fabricated and fitted, and does not restrict motion, the various components of the prosthesis are attached—(Fig. 13):

the hand,
the wrist joint,
the elbow joint, and
the shoulder joint.

At this time evaluation is made as to the degree of mobility of the various components connected together so that the prosthesis can assume all the positions required (Fig. 14).

If this objective is not achieved, it is necessary to add, by means of passive articulations, supplementary passive friction joints which render possible the positioning of the prosthesis to all the positions necessary for maximum functional capacity.

All this is absolutely necessary because the best prosthetic device made is completely useless if within the range of its functional capacity there are limits in its movements (Fig. 15).

Only after it has been demonstrated that the patient is capable of achieving a full range of motion (ROM) with his prosthesis, and of spatially controlling the prosthesis with his residual limb in all positions, and, above all when it is certain that the socket remains in place with no movement about the residual limb during operation of the prosthesis, do we proceed to determination of control sites or methods for operation of the various components such as the hand, wrist, and elbow. For example, when confronted with a shoulder disarticulation one must select three sites for three degrees of freedom of motion (hand, wrist, and elbow). Once sites are selected which have good myoelectric signals, the subject is trained to control the hand, wrist, and elbow, independently. Whichever muscle the subject is best able to use to control the elbow, for example, is the muscle site designated for the elbow. (Similarly, control sites for the hand and wrist are designated.)

As has been pointed out previously in this paper, the mechanisms and controls of the prosthesis must always be located on the affected side.

Before beginning installation of the control system it is important, first of all, to evaluate carefully the individual case. In the case of a unilateral congenital amputee, the function of the prosthesis almost always serves only as an aid to the remaining hand, or arm and hand. But in the case of bilateral involvement, the prosthetic devices are of vital importance.

The present state of progress in the development of myoelectric or electric prosthesis control has led, in the case of patients with congenital bilateral malformation of the upper limbs, to a consider-

FIGURE 15.—Adaptation of the prosthesis with further friction articulation (arrow). This enables the patient to position the upper arm passively in order to position the elbow and hand in a functional position, i.e., adds more freedom of motion.

able advantage as compared with other existing prostheses because it makes possible the utilization of both prostheses simultaneously—as well as independently, one from the other. This is possible because all the control systems of each prosthesis are to be found on the side of the prosthesis itself. For this reason, choice among control systems must be made with special care and adopted only after their various capabilities have been compared.

It is always important to begin with the simplest controls (from the point of view of activation and control) and then pass on to the more difficult ones, without unduly complicating the system in the

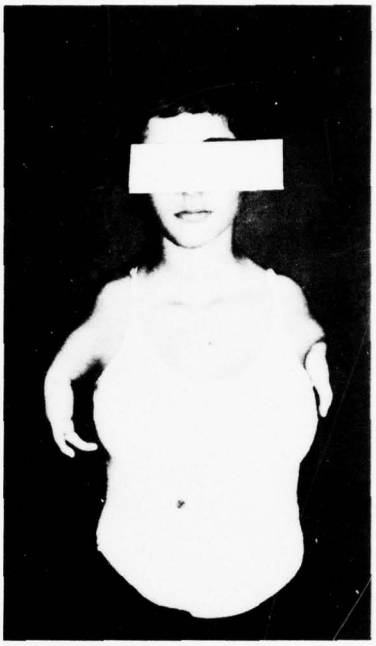


FIGURE 16.—In cases of congenital malformations of the upper limbs, account must be taken of the various systems of control for the prosthesis movements in peromelia (above), phocomelia (above, right), and amelia (right).

patient's eyes. Above all, avoid creating an unnecessary state of tension in the patient.

The application of prostheses for congenital malformations of the upper limbs can be divided into three large groups, each group with its particular system of control. The three groups (Fig. 16) involve (*i*) forms of peromelia, (*ii*) forms of phocomelia, and (*iii*) forms of amelia.

In the case of peromelia, where there exist residual limbs almost similar in form to those of a traumatic amputation, those residual limbs can be utilized for a myoelectric, mechanical, or kinematic control. In these cases use is generally made of the biceps and the triceps for single or multichannel myoelectric control for opening and closing the hand and for pronation and supination of the wrist, respectively. For extending and flexing the forearm and locking the elbow, movement of the residual limb is used. Because they have proved to be very satisfactory, we use Hosmer locking elbow joints in this particular application. For the very short residual limb having limitations in range of motion, a special system, which provides excursion amplification, makes possible the complete control of elbow flexion-extension and locking from 0 deg to 130 deg (Fig. 17). See also Figure 7.

Where there is bilateral peromelia, it has been necessary to develop a special device which, connected to the control cables, makes it possible to operate both elbows simultaneously as well as independently (Fig. 8 and 9).

Only when it is not possible to follow the procedure just described is it necessary to utilize an electric elbow. It must be pointed out that experience has shown, in forms of peromelia, that it is unlikely in their present state of development for an elbow dependent on external energy (in our case electric energy) to give movement as smooth as that controlled and powered by the residual limb itself.

In forms of phocomelia, we are faced with a different situation in which the malformed limb (almost always without skeletal connection with the trunk) can be utilized solely to activate control mechanisms for the various joints of the prosthesis.

In a very few cases, the small malformed limbs can also be used to control movements of the prostheses, in the same way as in forms of peromelia. In these types of malformation it is rare that one can use myoelectric controls. Certainly one *could* use rotator cuff or shoulder girdle muscles as a source of a signal, but that

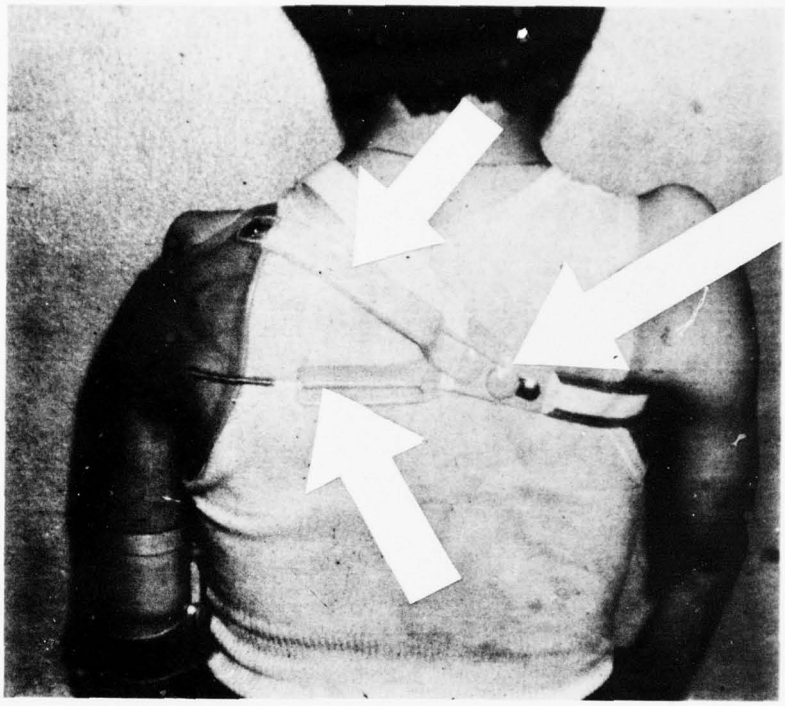
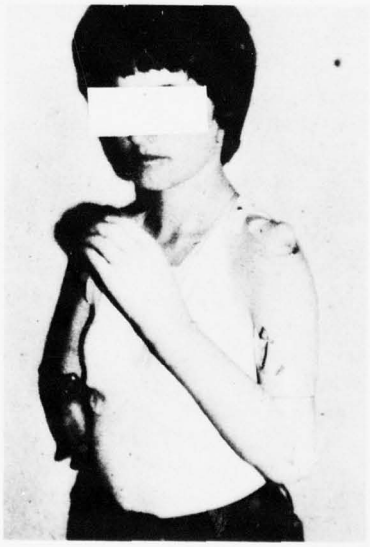


FIGURE 17.—A control mechanism which provides excursion amplification enabling full range of motion of the elbow in cases of very short residual limbs. At right: illustrating the prosthesis in use. Above: the multiplication system (excursion amplification). The arrow at right locates the pulley, and the pair of arrows at the left indicate the course of the control cable.



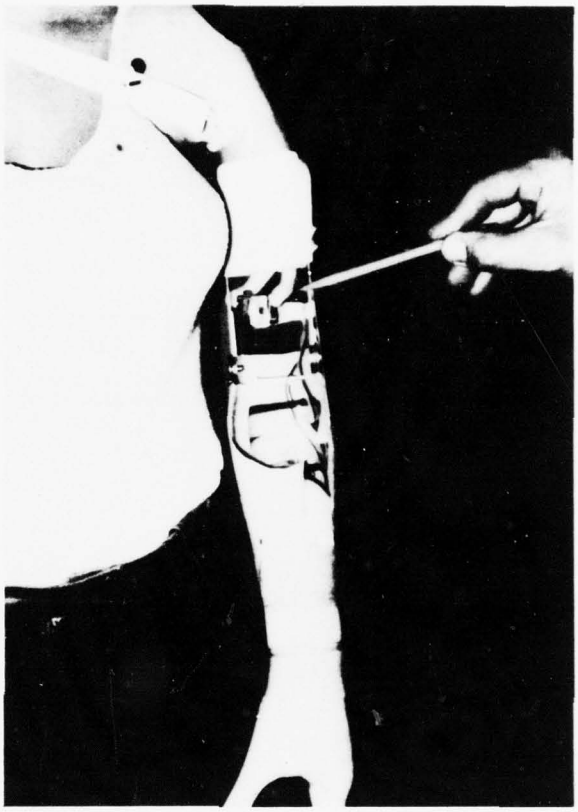


FIGURE 18.—Illustration of the use of microswitches in the control of a prosthesis for phocomelia.

would make it necessary to encapsulate the shoulder in the socket, thereby sacrificing range of motion. Therefore, instead of myoelectric controls, small microswitches or sensors are used. These are especially suitable because, for their operation, it is possible to make use of malformed parts of single fingers which, though without any strength, are capable of making a movement, however slight, to actuate the controls (Fig. 18).

For this reason it is possible to state with assurance that the prosthetic device for bilateral phocomelia has been considerably reduced as regards bulk. Improvement has been made in its func-

tion and appearance and, consequently, in the outward attitude of the disabled person toward his prosthesis—which also means improving the patient's functional capacity with his prosthesis.

In forms of amelia, use is made exclusively of myoelectric controls for the various movements, since up to the present no other system of control or combination of controls has given more satisfactory results.

Today it can be said that in the most serious dysmelic malformations such as amelia, the possibilities of achieving functional capacity have been improved by virtue of myoelectrically controlled prostheses. This has come about because, on the residual limb (in this case the shoulder) slight movements such as the forward and backward or elevation motions have been utilized by means of special sockets, and are of considerable importance for the functional capacity of the prostheses themselves.

Generally speaking one succeeds by using five pairs of electrodes (Fig. 19), with a multichannel amplifier, to control ten movements. This is amply sufficient for the entire arm.

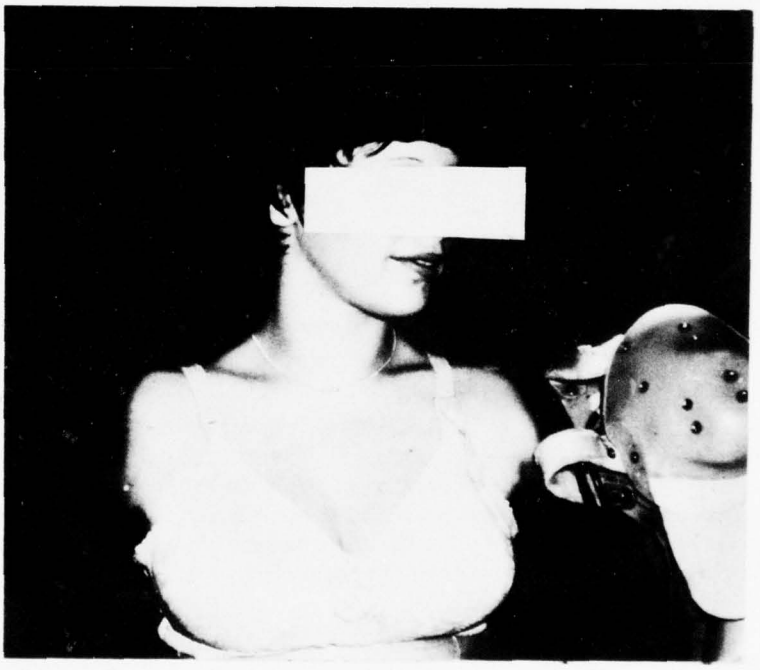


FIGURE 19.—Socket for a patient with amelia: five pairs of electrodes are clearly visible.

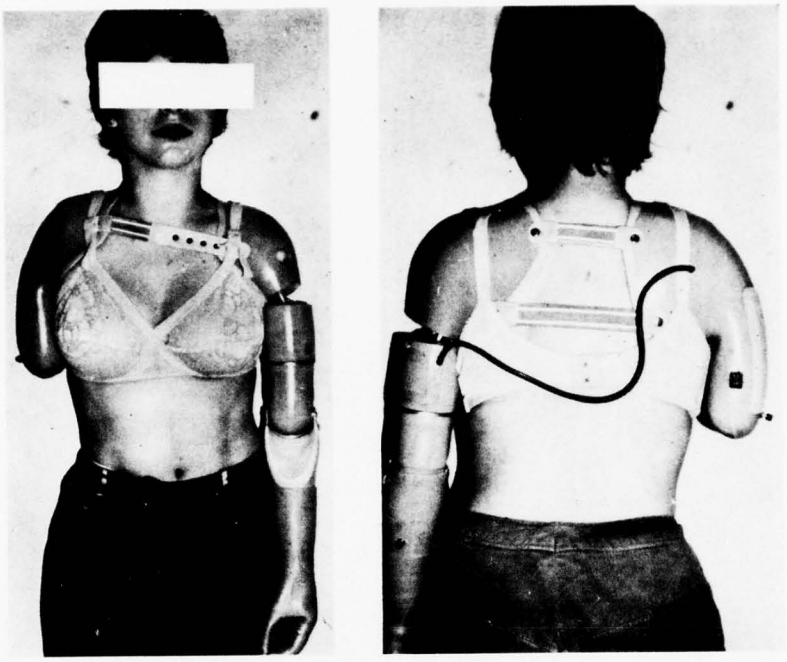


FIGURE 20.–Prosthetic treatment of one side, as initial phase, in a case of amelia.

Here again, it is only after a certain period of training the patient in the use of the various muscles that the entire prosthesis is constructed and the control site for each motion selected. Prosthetic treatment is carried out on one side first (Fig. 20). Then, after an interval of about 6 months, the other prosthesis is fabricated. The reason for this is to enable the patient to concentrate his entire attention on the operation of one prosthesis. Only after a suitable period of practice is he fitted with the second prosthesis and trained in using two prostheses simultaneously (Fig. 21).

The patient is also given the possibility of voluntarily eliminating movements such as those of the hand or the elbow, of pronation and supination, by means of microswitches or traction (pull) switches (Fig. 22 and 23). This temporary elimination of certain movements, willed and controlled by the patient himself, gives him a degree of assurance in certain uses of the prosthesis without upsetting the smoothness of the movements it is desired to accomplish.

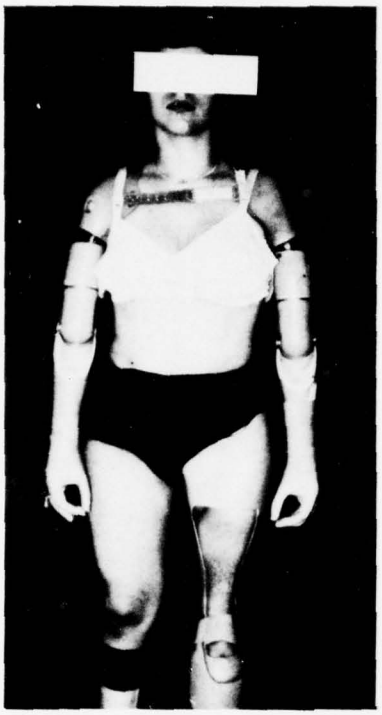


FIGURE 21.—Bilateral prosthetic management after an interval of about 6 months.

In practice this system makes possible the control of all the single movements without limitations. It also makes it possible to lock and eliminate within the prosthesis itself certain movements as compared with others.

CONCLUSION

In conclusion, it is possible to state that myoelectric and electric control systems have given a strong impetus to successful prosthetic restoration of congenital amputees. But, it is also necessary to point out that it is very unlikely that this kind of management can be carried out except in specialized centers. For the construction of these prostheses, in addition to highly qualified personnel in certain disciplines or branches of science, costly equipment is necessary. The small number of cases of severe dysmelia to be found in each country might not justify purchasing this equipment. Therefore, specifically to limit costs and reduce the burdens of amortization, it

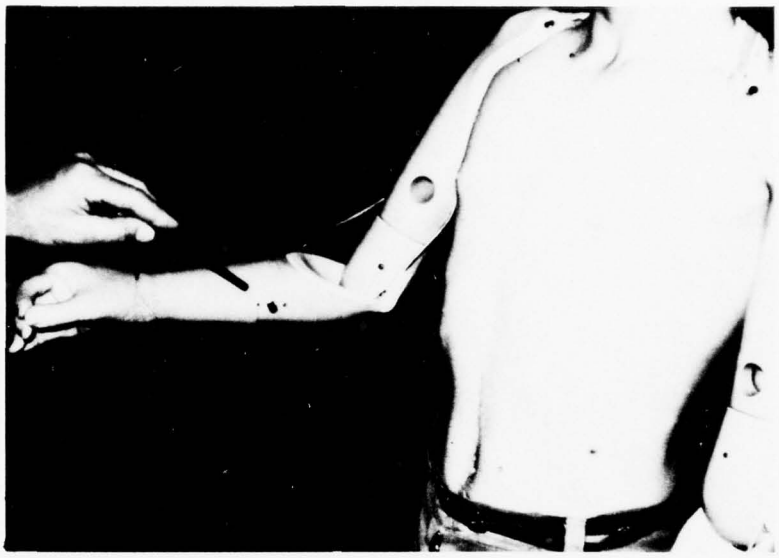


FIGURE 22.—Adaptation of a microswitch for the exclusion of certain movements of the prosthesis. It is located in the forearm and is manually operated by the other arm or by using the edge of a table, etc.

would seem logical to consider carrying out treatment on an international level.

At the present time we are in a position to treat the various forms of dysmelia of the upper limbs from the age of about 13-14 years and on. For younger children (fortunately few in number) the components do not exist, or rather, a beginning has only just been made in this direction. Here I should like to mention the Variety Village Electro-Limb Production Centre in Canada, which has undertaken the manufacture of components for electric prostheses for small children. We are just now at the stage of testing these components for inclusion in our program of prosthetic management of dysmelic children.

We are convinced that future prosthetic management, of both upper-limb traumatic amputation and of persons disabled by congenital malformation, lies with prostheses activated by electrical energy. We are confirmed in this conviction by the results of the prosthetic management of persons affected by congenital malformations of the upper limbs who have been supplied with myoelectric or electrically controlled prostheses.

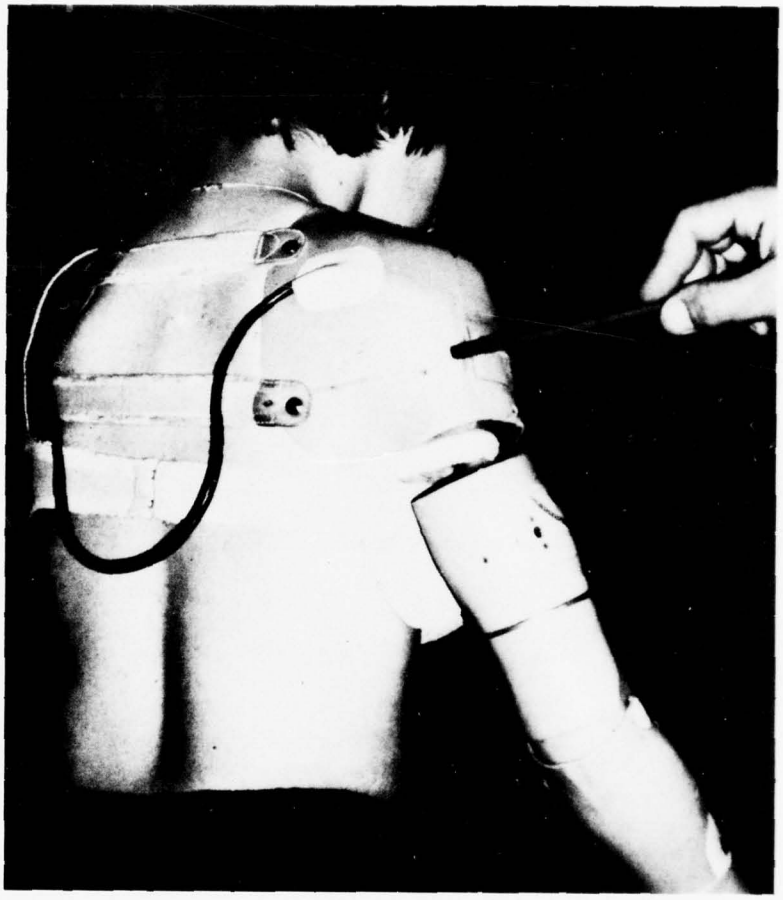


FIGURE 23.—Traction (pull) switch or microswitch which makes possible the voluntary elimination of certain functions of the prosthesis (such as the elbow or the wrist).

In the application of such complex prostheses, it must never be forgotten that the patients we treat are human beings, handicapped as a result of their malformations with the loss of dexterity, manipulative ability, and proprioceptive feedback. To compensate for their restriction of movement they have developed a sensibility that is more acute than that of physically normal people. They will give their cooperation as long as they feel the effectiveness and the benefits of the prosthetic restoration. They react adversely if they are disappointed with the device—and we must strive to see that this does not occur.

A SURVEY OF LOWER-LIMB AMPUTEES: PROSTHESES, PHANTOM SENSATIONS, AND PSYCHOSOCIAL ASPECTS[a]

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INTRODUCTION

Periodic evaluation of accumulated data allows not only for the detection of trends, but also for the constant monitoring of quality control of amputee service. Research in prosthetic design is always continuing. Modifications of prostheses to give greater functional ability and improved cosmesis, as well as provisions for recreational prostheses, are often mentioned in the literature. But is the patient satisfied with what has been and is being done for him to achieve maximum function, comfort, and esthetic appeal?

The purpose of this survey was to obtain information which would be helpful in evaluating various services delivered to amputees, and to determine whether the patients felt these services were adequate. An attempt was made to determine the number of patients for whom prostheses were prescribed; the length of time from surgery to prosthetic prescription; how long prostheses lasted; what modifications were necessary; and, most importantly, whether the patient was happy with his artificial limb.

Additional areas of investigation included the nature of phantom pain experienced and its relationship to prosthetic use; patient social readjustment and self-image; and, finally, patient suggestions for prosthetic research.

[a]Based on work performed under Veterans Administration Contract No. V663P-784.

MATERIALS AND METHODS

Questionnaires were mailed to 350 patients who had undergone a variety of lower-limb amputations. All patients had been treated with rigid postoperative dressings. The amputations had been performed at several Seattle-area hospitals, including the Veterans Administration Hospital and a children's hospital. Prostheses had been fabricated at a number of private and institutional prosthetic facilities.

Patients were invited to answer all relevant questions, with assurance that the identity of those responding would remain confidential. Personal interviews were arranged for those people who had difficulty understanding the questions.

Patient selection was limited to those who had been discharged from rehabilitation at least 3 months before the questionnaires were dispatched, affording patients adequate opportunity to return to their regular activities and to define their feelings.

In the interest of simplicity, description of amputation level was limited to three categories:

1. Below-knee—to include partial foot, Syme, and below-knee amputations.
2. Above-knee—to include knee-disarticulation, above-knee and hip-disarticulation amputations.
3. Bilateral—to include combinations of the above.

RESULTS

Patient Sample

To the 350 questionnaires mailed, there were 156 responses (45 percent). Twenty-two patients for whom a response was made had expired, leaving a total of 134 reported cases (38 percent of 350) who had undergone 154 definitive amputations.

Of the total sample, 103 (77 percent) were males and 31 (23 percent) females. Age at time of amputations ranged from 3 to 89 years of age, with a mean of 44.6 years and a median of 51 years. Average age of the below-knee group was 47.2 years; above-knee, 43.4 years; and bilateral, 49.5 years. Patients ranged from 6 months to 12 years postamputation at the time of this evaluation. (Fig. 1.)

Etiologies consisted of 10 (7.5 percent) congenital; 11 (8.2 percent) tumor; 48 (35.6 percent) trauma and post trauma; and 65 (48.7 percent) peripheral vascular disease (31 had previous failed vascular surgery, while 22 had diabetes—of these 7 had had failed vascular procedures).

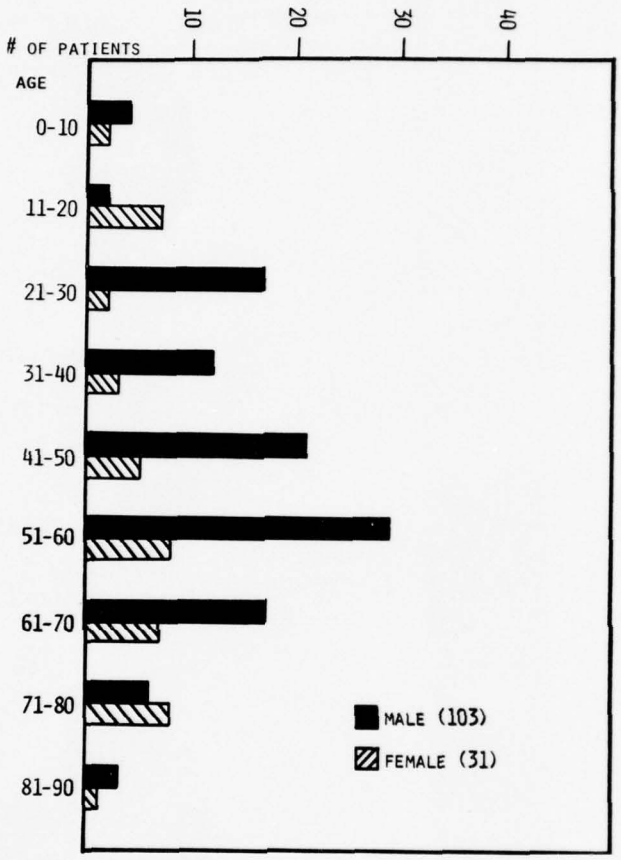

FIGURE 1.—Sex, and age at amputation, of patients whose responses were included in the survey. There were 134 reported cases, who had undergone 154 definitive amputations, in the total sample. In this graph, age at each amputation was plotted separately, as the amputations of most bilateral amputees were performed at different ages.

Below-knee amputations totalled 87 (65 percent); above-knee amputations, 27 (20 percent); and bilateral amputations, 20 (15 percent). (Fig. 2.)

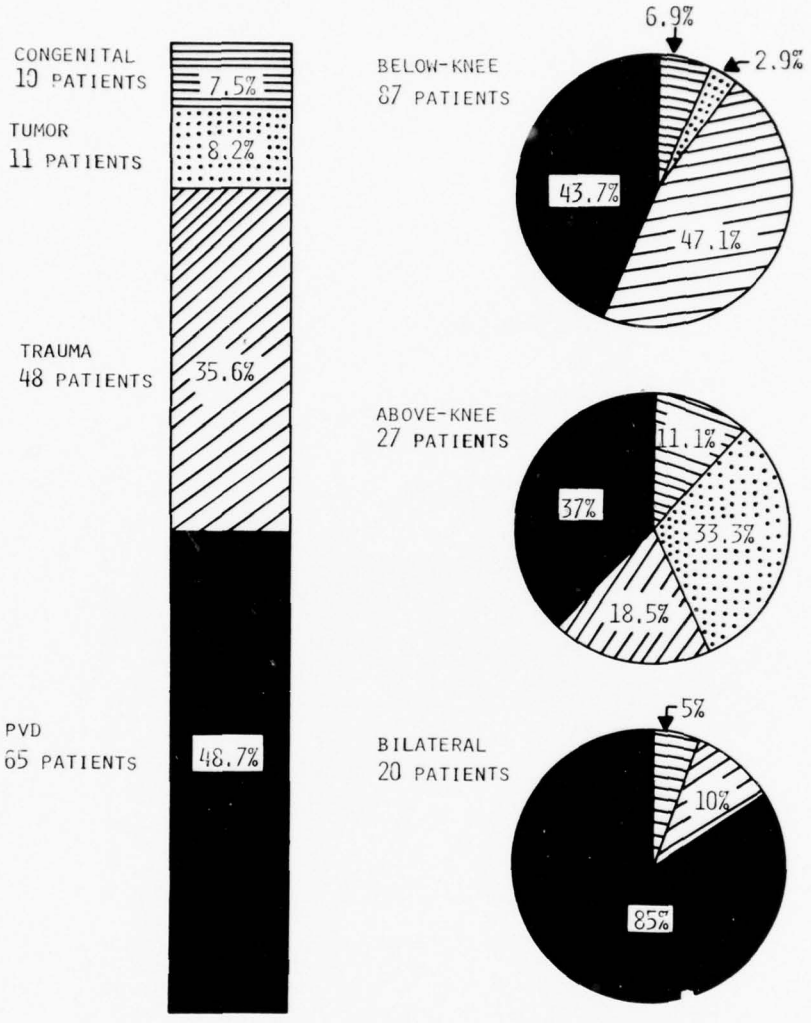

FIGURE 2.—Level and etiology of amputations.

Prosthetic Information

How Many Patients Wore Prostheses?

Of the total sample, 122 patients (91 percent) wore their prostheses; 108 patients wore them all day and the remaining 14 averaged

1 h to 6 h of use per day.

Two patients (1.5 percent) did not have definitive prostheses prescribed; one was a 74-year-old diabetic with bilateral above-knee amputations and one an above-knee amputee with hemiparesis. The remaining 7.5 percent (four bilateral amputees and six above-knee amputees) had prostheses but did not wear them. Five of these patients stated that they had poor prosthetic fit; two had sufficient pain in the "normal" limb to prevent ambulation; two were blind diabetics; and one could not afford a new prosthesis.

Time Interval Between Surgery and Prosthetic Prescription

There were 117 responses to this question. The average time interval from surgery to cast and measurements for definitive prostheses was 39 days, with a range of 14 days to 10 months. The 10-month interval was for a hip-disarticulation patient whose body

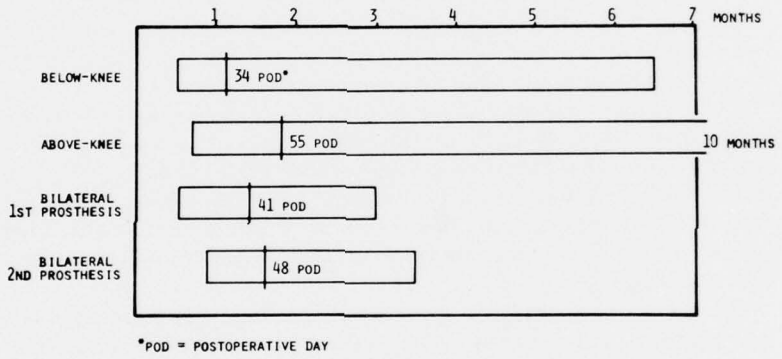

FIGURE 3.—Time interval between surgery and prosthetic prescription. The length of each horizontal bar indicates the range in lengths-of-time reported by patients in that particular amputee group. The vertical cut through the bar indicates the location on the time-scale of the average patient experience in that group: that average figure is the number shown in the bar. Average for all patients reporting was 39 days.

TABLE 1.—*Time Interval Between Surgery and Prosthetic Prescription*

	Range (Days)	Mean
Peripheral vascular disease	21 to 300	52
Trauma	22 to 193	45
Tumor	21 to 90	42
Congenital	14 to 36	25
0-30 year age group	14 to 193	37
31-55 year age group	14 to 300	55
56-years-and-up age group	21 to 180	46

weight had fluctuated widely due to kidney failure. (Fig. 3 and Table 1.)

Types of Prostheses Prescribed

In the below-knee group, one patient wore a partial-foot shoe filler and the five Syme amputees wore closed Syme prostheses. The remainder of the 87-patient below-knee group wore the following types of prostheses:

1. 29 patients (33.3 percent); PTB hard socket, of which 27 patients had cuff suspension;
2. 19 patients (21.8 percent); PTB socket with soft insert and cuff suspension;
3. 13 patients (14.9 percent); PTB with side joints and lacers;
4. 11 patients (12.8 percent); PTS socket with soft insert and built-in wedge, of which 2 had cuff suspension;
5. 9 patients (10.3 percent); PTS hard socket with wedge suspension, of which 5 had additional cuff suspension.

Twelve patients (14 percent of the below-knee group) used muscle contraction as a means of auxiliary suspension.[b]

Twenty-nine patients (33.3 percent) used waist belts as necessary added suspension. (This group included approximately 33 percent in each group of patients who wore either a PTB hard socket, PTB socket with soft liner, or PTS hard socket with wedge, and 76.9 percent of those patients who wore side joints and lacers. One patient used a shoulder harness with his PTB socket, soft liner, and cuff suspension prosthesis.[c])

Of the 27 above-knee amputees, 12 patients (75 percent) used full suction, and the remainder used semi-suction sockets, (i.e., semi-suction incorporates a suction valve and one stump sock). Knee mechanisms included 10 hydraulic, 4 mechanical, 1 pneumatic, and 1 manual knee lock. (All patients using hydraulic knees had full suction suspension.) The mean age of the patients wearing hydraulic knees was 31.8 yr; mechanical knees, 62.3 yr. Age of the patient wearing a manual knee lock was 68 yr and the patient using a pneumatic knee, 63 yr.

The 33 percent of the patients who used full suction required auxiliary suspension, while 50 percent of those patients with semi-suction sockets needed additional suspension; i.e., eight Silesian bandages and two shoulder harnesses.

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[b]These patients were encouraged by a physical therapist to use their muscles by doing isometric exercise.

[c]This patient was a 49-year-old male with a history of epilepsy who felt he needed this type of suspension as a safety precaution.

Of the 4 hip-disarticulation patients, 3 wore Canadian hip-disarticulation prostheses, and one wore an endoskeletal system (an Otto Bock modular system with flexible plastic socket and free-swinging knee).

In the 20-patient bilateral group, all symmetrical amputees were wearing the same type of prosthesis on both sides. There was no majority of one type of prosthesis over another: 3 patients wore PTB hard sockets; 2 wore PTBs with soft liner; 2, PTS hard sockets; 4, PTSs with soft liner; and 1, PTBs with side joints and lacers.

Forty-six percent wore waist belts for auxiliary suspension.[d]

Among the patients evaluated, the number of stump socks worn ranged from 0-25 ply, with an average of 6-ply. (The patient wearing 25-ply stump socks was a 42-year-old male who stated that he had lost 40 lb of body weight. He also stated that he was "too busy" to visit the limb company to be measured for a new limb.)

Recreational Prostheses

Patients were asked if they used any special adaptations or special prostheses for recreational activities. While 82 patients (61.2 percent) were active in a variety of sports (the most common were fishing and swimming), only 5 of them used special prostheses or assistive devices; i.e., swim fins for scuba diving, and special outriggers for snow skiing.

Modifications to Prostheses

The question concerning prosthetic modifications done by patients themselves yielded several answers. A total of 16 percent said they had made their own adjustments, including 18 percent of below-knees, 7 percent of above-knees, and 25 percent of bilaterals. Although patients were not asked why they chose to make their own modifications rather than go to a prosthetic facility, one patient did volunteer that he thought repair costs were excessive. Modification materials included foam rubber, felt, carpet fabric, and paper wedges. Several patients sanded "high spots" to decrease irritation. One patient claimed he reduced the weight of his prosthesis by 2 lb but did not explain how. Another patient drilled 21 holes in the socket and liner for ventilation—and had to resort to a waist belt for auxiliary suspension. Several patients removed straps which they considered unnecessary.

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[d]A bilateral Symes amputee wore two closed Syme prostheses with removable liners. An AK-BK amputee was wearing a PTS hard socket with wedge suspension and a partial suction quadrilateral socket with a pelvic band and a mechanical knee unit.

How Long Did Prostheses Last?

One hundred and twenty prostheses which had been replaced as worn out were evaluated to determine durability. (Patients still wearing their original prosthesis were not included.) The length of time ranged from 1 month to 12 years, with an average of 3 years. The prosthesis which lasted 1 month was a PTB with soft insert and cuff suspension for a 69-year-old male. The 12-year-old prosthesis, a PTB with side joints and lacers, had been worn by a 70-year-old male.

Syme prostheses had lasted from 6 months to 7 years with a mean of 2.91 years; below-knee prostheses from 2½ months to 9 years with a mean of 2.66 years; and above-knee prostheses from 3 months to 4 years with a mean of 1.87 years. Standard deviation for Syme prostheses data was 2.51; for below-knee prostheses, 2.05; and for above-knee prostheses, 1.17.

When prosthesis durability was evaluated by age group, the 0-30 age group had prostheses which lasted from 3 months to 7 years with a mean of 2.07 years; the 31-55 year group, from 3 months to 9 years with a mean of 3.23 years; and the 56-years-and-over group, from 2½ months to 5 years with a mean of 2.13 years.

Prosthetic Comfort and Satisfaction

Patients were asked if their prosthesis was comfortable (Table 2), and 25 percent of the group said they found it uncomfortable.

TABLE 2.—*Was Prosthesis Comfortable?*

	Below-Knee	Above-Knee	Bilateral	Total
Yes	58 (67%)	13 (59.1%)	9 (69.2%)	80 (65.6%)
No	22 (25%)	8 (36.4%)	–	30 (24.6%)
Moderate	7 (8%)	1 (4.5%)	4 (30.8%)	12 (9.8%)
	87	22	13	122

Patients were also asked if they were satisfied with the overall results achieved from surgery, prosthetics, and physical therapy. Of 131 responses, 21 patients had complaints about surgical results, i.e., adhesions, neuromas, and pain. The 12 complaints about physical therapy concerned only one point: they felt they were not treated for an adequate period of time. (Patients reported receiving physical therapy for periods ranging from "no treatment" to 4 mo with an average of 6 wk.) There were 42 complaints about prosthetists and prostheses. Dissatisfaction was most predominant among the above-knee amputees (Table 3). One patient described wearing his prosthesis as like "standing in a giant fiberglass teacup."

TABLE 3.—*Prosthetic Satisfaction*

	Below-Knee	Above-Knee	Bilateral	Total
Yes	64 (75%)	10 (38%)	12 (67%)	86 (66%)
No	20 (23%)	16 (62%)	6 (33%)	42 (32%)
Moderate	3 (2%)	–	–	3 (2%)
	87	26	18	131

Phantom Sensation/Pain

Several questions were asked in an effort to determine the extent of phantom sensation and/or pain. Twenty-four patients (18 percent) experienced no phantom sensation, while 17 patients (13 percent) required medication for control of pain (Table 4). The patients who used pain suppressants constituted 13 percent of the male population and 13 percent of the females; 11.5 percent were below-knees, 18.5 percent were above-knees; and 10 percent were bilateral amputees. According to etiology, 17 percent of the patients had peripheral vascular disease, 6 percent had traumatic injuries, and 27 percent had tumors.

TABLE 4.—*Analysis of all Patients Requiring Pain Medication*

AGE	Level	Sex	Cause	Work
(44)[1] 52[2]	BK	M	PVD	Retired
(65) 74	BK	M	PVD	Retired
(61) 70	BK	M	PVD	Retired
(48) 53	BK	M	PVD	Unable due to amp.
(67) 72	BK	M	PVD	Retired
(77) 80	BK	M	PVD	Retired
(47) 50	BK	M	PVD	Retired
(38) 40	BK	F	Trauma	Unable due to amp.
(33) 34	BK	M	Trauma	Unable due to amp.
(68) 71	BK	M	PVD	Yes, but changed
(70) 79	AK	M	PVD	Retired
(60) 67	AK	M	Trauma	Retired
(65) 71	AK	M	Tumor	Retired
(61) 63	AK	F	Tumor	Part time work
(72) 74	AK/AK	F	PVD	Retired
(53) 61	HD	M	Tumor	Retired
(51; (52) 56	BK/AK	F	PVD	Unable due to amp.

[1] Age at time of amputation

[2] Present age

When describing phantom sensation, results were divided into two groups, those patients wearing prostheses and those not wearing them (Fig. 4). Of those patients wearing prostheses, 10 percent required medication, whereas, 42 percent of those not wearing prostheses used medication for pain control. Less than 20 percent

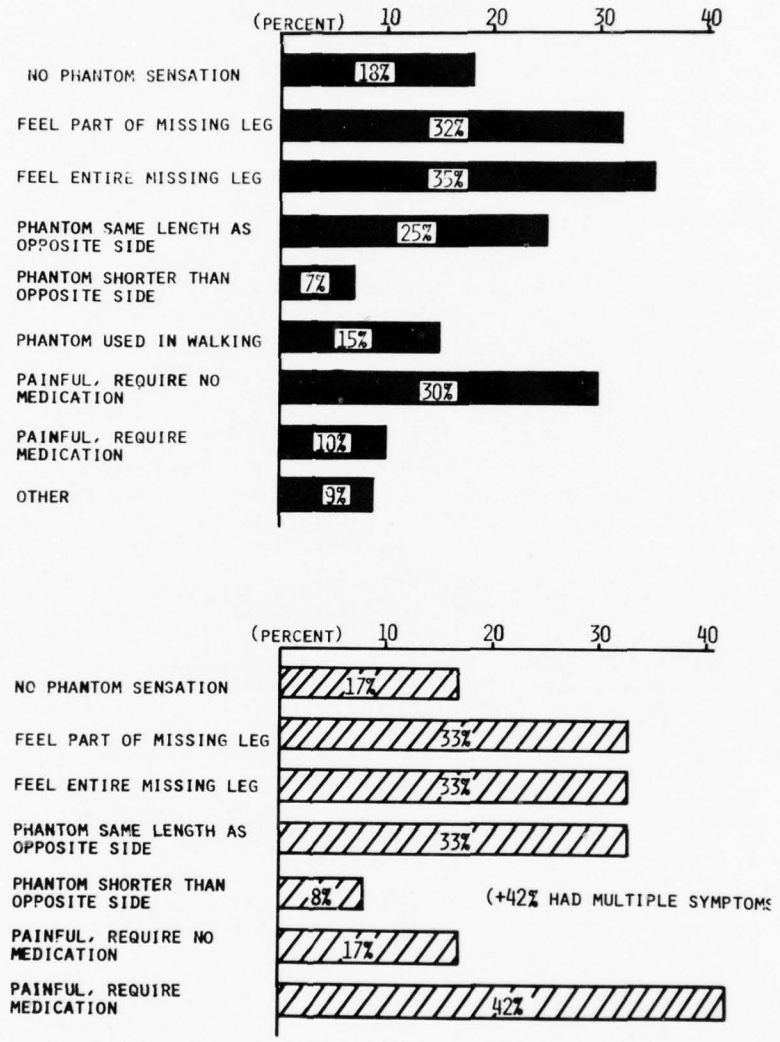

FIGURE 4.—Phantom sensation and pain, as reported by the 122 patients who wore their prostheses (solid bars), and by the 12 patients who did not wear prostheses. (Percentages refer to the distribution of a particular symptom among the patients in a group. Note that among patients in the group wearing prostheses, 48 percent had multiple symptoms; in the group not wearing prostheses the percentage with multiple symptoms was 42.)

of each group experienced no phantom sensation. Symptoms in both groups were very similar—i.e., in each group, 33 percent were aware of only part of the missing leg; another 33 percent were aware of the entire missing leg; 25 to 33 percent felt that the phantom limb was the same length as the opposite side; and less than 10 percent considered the phantom side shorter than the "normal" side.

Of the patients wearing prostheses, 15 percent actually used phantom sensation for ambulation.

Psychosocial Aspects of Amputation

Steensma (1) stated "The problem is not entirely solved by our providing adequate surgery, excellent postoperative care, expertly fitted modern prostheses, and the latest training techniques. It would seem that a careful investigation of the psychological and social factors involved is essential."

Questions related to this premise were asked of the patient to determine how he felt about himself and how he perceived that other people responded to him.

1. *Do You Feel Handicapped?*

An important determining aspect of an amputee accepting his condition is whether or not he feels handicapped in leading a "normal" life. This question was phrased in a "yes" or "no" fashion, but also providing space for explanation (Table 5). The majority of people did not feel handicapped.

TABLE 5.—*Do Patients Feel Handicapped?*

	Below-Knee	Above-Knee	Bilateral	Total
Yes	23 (28%)	10 (38%)	12 (60%)	45 (35%)
No	60 (72%)	17 (62%)	8 (40%)	85 (65%)
	83	27	20	130

Some of the more notable responses were as follows:

"If you have a good prosthetic fit, you can lead a full and normal life."

"I can adjust and do anything; pain is the only limiting factor."

"I lead a normal life, but get frustrated and disgusted with the canes and the pain."

"The biggest problem of formerly active amputees is one of frustration . . . how to sublimate . . . what now are my assets . . . where should I now emphasize my efforts?"

"You are only handicapped or deprived if you want to be. The

public labels us as being handicapped; therefore, we have to 'prove' ourselves."

"My clothing and physical activities are markedly restricted."

"No one will employ me."

"Can't go shopping or to church. Have to rely on the radio for church services."

"Cannot travel freely."

"No problems with everyday living, but I have to hire help for anything extra."

"Can't do anything—no women, no drinking."

"Feel like I delay others when invited on outings."

"Don't feel relaxed in crowds."

2. *How Do You Feel Family, Friends, and the Public Respond To You?*

Interpretation of limb loss transfers from family, friends, and the public to the amputee, creating either negative or positive feelings with respect to his own self-concept.

The majority of patients in this sample stated that no change in relationships occurred after amputation. Of those patients who did notice a change, terms most commonly used were "curiosity, sympathy, overprotectiveness, indifference, consideration, and amazement." Some interesting responses were as follows:

"They think I am better off now than before amputation."

"Treated like an invalid, except by my wife."

"Treated like everyone else; just because crippled is no reason for pity."

"Some people feel sorry for me—I don't like that."

"They have been wonderful. No one has made 'exceptions' and our relationships have not changed, rather they have grown."

"Very well, they have given me confidence so that I can do almost anything."

"Sometimes sympathetic, most not caring or glad its not them."

"They respond to a person. I do not feel public owes me anything."

"Women tend to mother me; men feel frustrated and turn away."

3. *Suggestions from Patients*

Patients were asked to suggest how conditions could be improved for future amputees. There were wide-ranging responses.

Of 66 suggestions received there were 34 requests for better comunication. These included the following: "Rap groups" either with staff or with other amputees; more parental and vocational counseling; greater distribution of written resource materials;

improved communication between prosthetic facilities and research centers; greater utilization of engineers in prosthetic design; greater patience and understanding from prosthetists; and more home visits from physical therapists because "therapists often have ideas for conquering 'everyday garbage.' "

Patients felt they should have been warned about the following:

1. Everything will not necessarily be wonderful after amputation.
2. Amputation does not remove peripheral vascular disease.
3. There are possible complications from surgery.
4. They will endure physical and mental fatigue.
5. Phantom sensation is normal.
6. The prosthesis will fall off occasionally; i.e., loss of suction when doing twisting actions.
7. Seating in restaurants is often inadequate due to confined spaces, chairs without arms, and restrooms a flight of stairs away.
8. Not everyone in society will view them fairly.
9. Society will often label them handicapped.

4. *Direction of Research*

Finally, patients were asked in what direction they felt personnel in the prosthetics research field should concentrate their efforts.

A small number of patients requested more investigation into the disease processes themselves, into the nature of phantom pain, and the possibilities of limb transplants. Further research on the use of Controlled Environment Treatment was encouraged by three patients.

There were 43 patients who asked for more research in the fabrication and design of prostheses; 9 patients wanted lightweight prostheses; 2 wanted more durability; 1, a better knee mechanism; 8 wanted better ankle; 4, less cumbersome prosthetic material; and 4, better cosmesis.

Two patients would have liked soft, less-shiny outer coverings. One patient felt "the SACH foot should become obsolete; when sitting in a chair, I cannot stretch my legs out because the toe sticks up in the air."

One woman asked why the suction valve on an above-knee prosthesis had to be red; "How can you wear short dresses with the red dot sticking out like a sore thumb?" A covering on the prosthesis to decrease hosiery damage was another suggestion. Seven patients wanted "a leg that breathes in the summer."

Further investigation into determining whether a hard socket or a socket with a soft insert is best was indicated by four patients.

Two people suggested teaching patients to make or repair their own prostheses. Several patients felt there was a definite need for price-control legislation for prostheses.

Regarding water sports, two patients wanted waterproof legs for swimming, and one man wanted a wetsuit that would fit around his prosthesis.

Last, but not least, five patients wanted research into bionic limbs.

DISCUSSION

Several matters of major interest have emerged from this study. The patient sample, although small, was comparable in terms of sex distribution, level of amputation, and etiology for amputation to that of the well-known "Amputee Census" of Glattly (2). The mean age at time of surgery for this sample was, however, slightly lower.

Lambert and Sciora (3) in a survey of 182 juvenile amputees, determined that the time interval between surgical amputation and prosthetic fitting varied from 1 month to 11 years, with most patients having been fitted within one year. Davies, et al. (4), in a study of 8,323 amputees found that the median period to prosthetic delivery was 6 months, and that the median time lapse was 5 months for the below-knee prostheses and 6 months for all other levels. Congenital amputees received prostheses in a median time of 3 months postsurgery, while patients in the disease category waited the longest period of time, 6 months. The results presented here showed the same trends, but time intervals were *considerably* reduced. These improvements may be related to two factors; i.e., increased number of prosthetic facilities, and greater utilization of Immediate Postsurgical Prosthetic Fitting as a mode of postoperative treatment.

Chapman, et al. (5), in a survey of 51 geriatric amputees, found that 44.7 percent of the patients were never fitted with a prosthesis. Walters (6) had 15 patients (20 percent) in his study who were advised against using a lower-limb prosthesis by the institutional staff. In the present study, only 1 percent of the patients did not receive definitive prostheses.

Of those patients who did have prostheses prescribed, 91 percent of the present sample were actually wearing them, as opposed to 70 percent reported by Kihn, et al. (7). Where several below-knee amputees in Kihn's study rejected their prostheses, none in the present study did. Of the 10 patients not wearing their prostheses, 6 had either prosthetic problems or difficulties in meeting costs,

while 4 had other medical problems not related to their amputation.

The only other survey describing type of prostheses prescribed was that done by Davies, et al. (4). Below-knee prostheses were similar for both studies. A question often asked in amputee clinics is whether or not to make a soft liner for the socket. The present study showed a very slight preference for hard sockets. Pelvic bands as a means of suspension in above-knee prostheses were used by 56 percent of the patients in Davies's study—that was a definite contrast with the present study where all patients used either total or semi-suction sockets, and, if auxiliary suspension was necessary, a Silesian bandage was used. The most frequently used knee component reported by Davies was a mechanical knee; the present study revealed a greater utilization of hydraulic mechanisms, probably due to greater knowledge and availability of devices.

Only a very small percentage of patients used special equipment for recreational activities. Several patients were not aware of available adaptive devices. The extra cost of ski legs (not covered by insurance) presented a problem to one patient. Most people did not know that prostheses could be made of waterproof material. There appears to be a definite need for greater dissemination of new information about recreational prostheses both for patients and health care professionals.

As a patient becomes more dependent on his prosthesis for protection of his residual limb and for return to a more normal status, the prosthesis approaches becoming a part of him. Thus, it is very important that the patient's limb be comfortable and that he be satisfied with it, both functionally and esthetically. Present results revealed that 25 percent of the sample were extremely uncomfortable, while an additional 10 percent were moderately comfortable, and 33 percent of the patients were dissatisfied with their prosthesis. The only comparable statistics available were those of Lambert and Sciora, who in their study of juvenile amputees reported that 26 upper-limb amputees (40 percent) were dissatisfied with their prostheses, while 10 lower-limb amputees (8.4 percent) were dissatisfied. The state of the art has improved considerably over the years, but there is still a definite need for more innovations, and for concern about patient comfort, especially for the above-knee amputee.

In an analysis by Jolly, as quoted by Gillis (8), of 2700 primary amputations, he found a painful phantom limb in 13 percent, a painless phantom sensation in 67 percent and no phantom in 20 percent of the patients. Pisetsky (9) made a rather extensive literature review on phantom sensation and noted that 86 patients in his series (95 percent) had phantom sensation and that 14 patients (15

percent) complained of pain. He also quoted Baily and Moersch whose study had 43 patients (86 percent) complaining of phantom sensations. Gallinek (10) stated that he had not seen an example of a phantom limb in a congenital amputation or a congenital absence of a limb because the cortical image of the missing limb had never been present. Kolind-Sorenson (11) stated that phantom pain was more common in above-knee patients than in below-knee amputees.

Results in the present study showed similar trends in percentages of patients experiencing phantom sensation and pain, as well as the lack of phantom pain in congenital amputees. In agreement with Kolind-Sorenson, more above-knee than below-knee patients had pain. It was interesting to note that gender had no effect on determining whether patients required pain medication or not. The information obtained did support a clinical observation that patients wearing prostheses have less phantom pain than those who do not.

Morgenstern (12) felt that age was a contributing factor in determining whether patients will have severe phantom discomfort. In his study, patients under 35 years of age experienced none. The youngest patient in the present study experiencing severe phantom discomfort was 34 years old, and the mean age of this group was 62 years. (The mean age for the total sample was 44.6 years.)

Another clinical impression is that diverting the patient's attention to a suitable occupation or avocation allows for less time to focus on phantom sensations. This impression was borne out by the present study, where only two, of those patients using pain suppressors, were employed.

Suggestions from patients included dissemination of information, better communication between hospital staff and patients, and improved prosthetic design. Several comments by Fishman (13) and Foort (14) on how amputees feel about amputations are reiterated in results shown here.

Surprisingly, there were no requests for elimination or improvement of stump socks. There were also no complaints about the use of assistive devices, i.e., canes, crutches, etc.

SUMMARY AND CONCLUSIONS

One hundred and thirty-four amputees, who were anywhere from 6 months to 12 years post amputation, were evaluated by means of restrospective questionnaire surveys. Patient population was similar to that of the classic "Amputee Census" in terms of sex, level, and cause of amputation; average age was slightly lower than that in most investigations.

Great improvements appear to have been made in the number of patients who receive prosthetic prescription as well as in the length of time between surgery and delivery of the prosthesis. On the average, younger patients were fitted sooner, while patients with peripheral vascular disease required a longer rehabilitation time.

Only a small percentage of patients rejected their prosthesis, and most wore it all day. Because there is little available material on special adaptive devices for the amputee, only a very small number of patients used any for sport activities. While most amputees were happy with results achieved from surgery and physical therapy, approximately 33 percent of the patients were dissatisfied with their prostheses, especially the above-knee amputees.

A contributing factor in determining whether patients will experience phantom pain appears to be whether or not they wear a prosthesis. In this small sample, a smaller percentage of patients who wore a prosthesis had pain than those who did not wear a limb. Of the patients who used pain medication, a greater number were not working. Older patients had more severe phantom pain.

Reactions and psychological adjustments to amputation were highly varied. Most patients stated that they did not feel handicapped.

There were strong indications for more psychological and vocational counseling, greater dissemination of available information, and considerably more work in prosthetic design; i.e., improvement of function, cosmesis, and comfort. Interest in bionic limbs and limb transplants was suggested by several patients.

While a greater number of amputees appear to be receiving prostheses rapidly than in the past, there are still many uncomfortable and dissatisfied patients. Perhaps now is the time to let the patient verbalize his complaints and to have the professionals attempt to remedy them. Much attention in the past has been directed at making limbs so that patients can walk. Obviously this is not the only activity an amputee performs during the day. Education may now need to be directed at facilitating more extensive recreational activities, either by research into better prostheses, or by improved training methods.

From the results of this study, wearing a limb for control of pain alone may be indicated. More extensive studies need to be done comparing pain in patients wearing or not wearing prostheses.

ACKNOWLEDGMENTS

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RESEARCH AND DEVELOPMENT IN THE FIELD OF READING MACHINES FOR THE BLIND

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ABSTRACT

Mauch Laboratories' Cognodictor reading machine for the blind has been redesigned to meet much higher standards of performance. Consequently, the new High Performance Cognodictor should satisfy the needs and expectations of a larger proportion of the veteran and non-veteran blind population.

Earlier Cognodictor designs had low cost as the dominant design criterion.

Significant progress has been made in the development of hardware and software for the new Cognodictor. A hand-held probe has been designed, built, and tested. Circuits which preprocess the video signal from the probe, and circuits which interface the probe with a PDP-11 minicomputer, have been built and placed in operation. Test and video display programs have been written and debugged. Routines in the recognition software which detect word spaces, locate character boundaries, and measure height and width of a character have been written and tested. More specific routines for the letters o, c, e, a, s, and t are being written and debugged.

It is planned to have the construction of a Cognodictor prototype parallel the completion of the software, using LSI-11 microcomputer hardware for character recognition, and 8080 microcomputer hardware with a Votrax synthesizer (which has been in operation at Mauch Laboratories) for speech production.

INTRODUCTION

The blind members of our society generally have low incomes and reading machines for the blind might be described as partial

replacements for relatively inexpensive systems of print access such as talking books, braille, and volunteer readers. In the past, Mauch Laboratories considered low cost as one of the most important design criteria for both direct-translation and recognition-type reading machines.

Earlier designs of Mauch Laboratories were considered quite successful in providing a good level of performance at low cost. For example, the Stereotoner, priced at $1,250.00, is half the cost of the Battelle Optophone and less than one-half the cost of an Optacon despite the much higher production level of the latter. Maximum reading rates of about 80-90 words per minute have been reported for both the Optacon and the Stereotoner, and average rates are comparable.

Utilizing only 130 low-cost integrated circuits, the first Cognodictor produced spelled speech for all the lowercase letters and most of the uppercase letters of about nine common styles of type. Considering its projected cost of about $4,000 in small quantities, its performance/cost ratio was considered excellent for its time.

The Two-Dimensional Multiple Snapshot Cognodictor extended the tolerance for mistracking by a factor of five and was designed using 19 type styles. Its output was to be spelled speech at rates up to 80-90 wpm (words per minute). Its cost was projected at $6,000. Before it could be completed, it became apparent that performance expectations had increased substantially and that cost was therefore much less a factor—at least, for the federal agencies and foundations which usually purchase and evaluate the first models of such devices. Accordingly, a new Cognodictor design was started in April 1976.

PROGRESS IN COGNODICTOR DEVELOPMENT

New Cognodictor Design

In April 1976, the sponsor approved changes suggested by Mauch Laboratories intended to lead to a reading machine with much higher performance—one which would have an error rate of less than one percent in letters and numerals of a wider variety of type styles. This High Performance Cognodictor was to have a synthetic speech output, with spelled speech or direct translation (tone code) outputs also available at the press of a button. The design called for two components—a high-resolution optical probe designed for hand-held use, and a control box containing two microcomputers and a Votrax vocal synthesizer. Initially the control box was expected to be about 2¼ ft^3 in volume and weigh 30-35 lb. The

Cognodictor's cost (in September 1977) is estimated at about $12,000 each in a quantity of 10. The price, size, and weight can all be expected to decrease substantially with the rapid progress apparent in electronics technology. Additional cost reduction should be possible with increasing production.

The designers believe that the combination of the hand-held probe of the Cognodictor and its direct translation output mode will combine to allow the user to understand the format of his document and decipher unusual symbols. In this mode, tonal or tactile patterns which correspond closely with the print will be produced. The vertical span covered by these patterns can be set by a user-operated magnification control, so that one line of print can be sensed at a time. The additional information conveyed in this mode would be difficult or impossible to obtain from an automatic page-scanning machine without a direct translation capability.

The Fairchild CCD-121 photocell array in the probe is designed to scan a band 1½ in high, thus providing a tracking tolerance of ±.675 in for typewriter-size print. This amount of tracking tolerance should make freehand tracking very fast and easy, eliminating the need for tracking aids in most cases. An automatic page-scanner, for use with long magazine articles and books, could be made available in the future.

The new Cognodictor design goals include a wider range of characters (including italics and numerals) over a wider range of type styles. The number of photocells used (~1500 from an array of 1728) permits both a large field of view and high resolution, which should yield reliable detection of lines as fine as .003 in (found in some common type fonts such as Caslon, Baskerville, Primer, etc.), even in the presence of interference from print on the other side. It can also allow adjustment for type size to be an automatic, electronic operation. (A manual override would be provided for use in direct translation mode when needed.) The photocells are sampled each time the probe moves .003 in horizontally as determined by an optical encoding disk which contacts a roller.

The design provides for automatic adjacent-line suppression based on information obtained by the photocells above and below the line being read. A similar process will be used for the automatic suppression of underlinings. This adjacent-line suppression can be overridden by a control on the main box, for the rendition (in the direct translation mode) of mathematical formulae, geometric figures, etc., covering more than one line-space.

Italics will not necessitate slanting the probe but will be automatically accommodated by the Cognodictor. The computer in the

Cognodictor will also be used to decide whether the print is typewritten (equally spaced) which will facilitate word separation (look for the middle of a letter location, if it is white it must be a word space)—or not typewritten in which case word and letter spaces are sufficiently different to avoid ambiguities in discovering word spaces. Touching letters will initiate a subroutine to separate and recognize them.

It is intended to have the Cognodictor's direct translation mode initially use 10 tones, as in the Stereotoner, but monaural. The tones will be initiated by pressing a button on the probe. Later, an accessory tactile display could be developed, possibly one which embosses a reusable plastic sheet or strip.

The usual output, synthetic speech, will be produced by a vocal synthesizer such as the Votrax unit. Its output rate will be adjustable up to 150 words per minute. An additional computer program will allow the synthesizer to produce spelled speech at up to about 40 wpm. The basic pitch of the voice would be adjustable by the user to his preference; changes above and below the basic pitch are machine-controlled.

The design calls for the speaking of a word to begin as soon as possible after the detection of a word-space, to eliminate delays which would be present if the program were to require the user to scan to the end of the line or to the end of the sentence. For this reason, and to keep the size and cost of the machine within reason, it is not intended to use syntactical analysis and stress assignments in the Cognodictor at the start. Punctuation marks will be recognized and their names pronounced only when the spelled speech mode is used.

Probe Design

From previous exposure to the optical probes or cameras of direct translation reading aids such as the Stereotoner or the Optacon, one might assume that a comparable probe would meet the letter recognition needs of the High Performance Cognodictor being developed. Actually, the Cognodictor requires a probe with much greater capability. The greater accuracy and higher reading rates of the Cognodictor require a faster photocell array with more resolution than slower direct-translation devices require or can utilize. And, at higher scanning speeds, the user cannot track as accurately, so the vertical extent of the array must be increased. Therefore, the new probe (Fig. 1) has many more photocells (1728 as compared to 144 in the Optacon), the field of view is greater (1.5 inches as compared to .750 in the Stereotoner and .225 in the Optacon), and the speed of response of the photocells is much faster (0.5 ms

as compared to 5.0 ms for the Optacon). The probe also contains an optical encoder—not required in the Stereotoner or the Optacon—which informs the Cognodictor of the distance and direction of each horizontal motion.

It might also appear that using a hand-held probe simplifies the Cognodictor design as compared with using an automatic page-scanner mechanism. Actually, the Cognodictor/probe combination

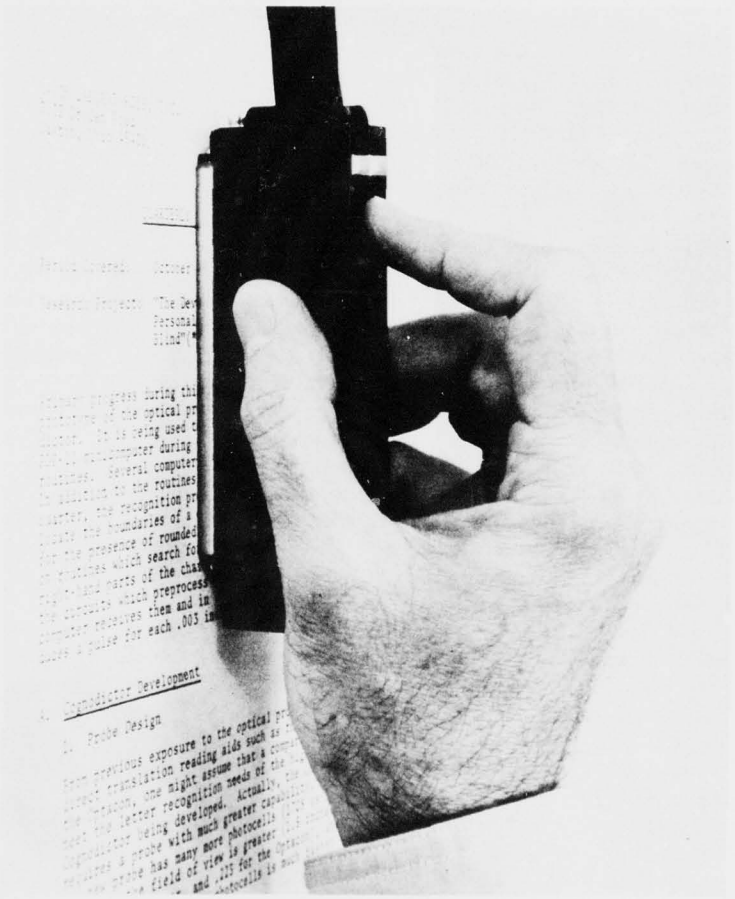

FIGURE 1.—The large field of view (1.5 in high) and long high-friction rollers of the Cognodictor probe make freehand scanning of print easier than ever.

is more difficult to design. Some of the reasons for this are given in the following comparisons between possible designs for probes and page scanners.

The illumination of the probe is limited to below about 2 W by the problems of disposing of waste heat, whereas the page scanner can use 20-50 W or more. In the page scanner uniform illumination can be achieved easily by diffusion and/or by moving the lamps several inches from the print: the probe must use efficient reflectors in a limited space.

The space available in a page scanner allows the use of an off-the-shelf lens designed for making close-up photographs with a 35 mm camera. The high level of illumination present allows the use of a small-aperture setting, and filters to remove infrared wavelengths, for a sharper image on the photocells. The space is also adequate to mount the photocell array directly to the circuit board that processes the signal, thus avoiding the electrical effects of a cable at a critical point.

The hardware and software designed for use with a probe must be able to handle a wide range of scanning speeds, while the page scanner may only have to function at one speed. For example, suppose both machines are to produce 150 wpm of synthetic speech and both are to scan typewritten pages with 10 characters per inch. To achieve this net rate, the probe user is expected to scan the typical 6-in line left-to-right in about 2 s, flyback and change to the next line in the next 2 s. This requires that he scan in the forward direction at 300 wpm or about 3 ips (inches per second). Actually, he cannot hold this or any other speed with precision, so the probe system should be designed for operation up to 6 ips. By comparison, the page scanner could scan and recognize in both directions at 2 ips and still produce 150 wpm with a 30 percent allowance for line change.

The designer of the page scanner also can be certain that each scan will be along a straight line with a preselected slope, so few photocells have to be allocated for possible mistracking, and the recognition program can be less complex than one which has to search over a larger area for a character feature.

Although these factors, among others, make the page-reader easier to design and build than the hand-held probe, the presence of an unlimited number of print formats among the materials the blind wish to read makes the probe concept worthwhile. It is expected that, after some training, the probe user will be readily able to scan new formats in reading matter, to locate short items in reference or text books, and to make sense of unusual indicia which are not recognized correctly by the machine.

The Cognodictor will have a page-scanner as an accessory, but with its hardware and software designed to meet the more stringent needs of a probe, adding a scanner should be relatively simple. Then, Cognodictor users will have the advantages of both systems.

Probe Construction

An optical encoder, which provides forward/reverse signals and clock pulses for each .003 in the probe rolls horizontally, has been designed and built. The success of the probe is very dependent upon the accurate and reliable operation of the encoder. Three months of continuous operation were used to test the durability of the encoder and associated circuitry.

Inside the encoder, a rotating transparent disk with 135 equal opaque sectors interrupts two beams of infrared light from two light-emitting diodes to two phototransistors. The interruptions produce square wave signals from the phototransistors which are equal except for being separated by a time displacement of one-quarter of the wave period (90 deg). A circuit detects which wave is leading the other in time and thus determines the direction of travel of the probe. Short pulses are produced by each edge of each waveform to mark the passage of each increment of .003 in.

The probe uses a reflex optical system with a 45 deg front surface mirror, a 20 mm focal length lens (later to be 18 mm) and a Fairchild CCD-121 photocell array. The magnification produced is 0.5×, a reduction of 2 to 1. In addition to the optical encoder and associated circuits, the probe contains two miniature switches and a circuit board containing an amplifier and several circuits needed to operate the photocell array. A flat cable about 1 in wide contains 20 wires which connect the probe to the Cognodictor circuitry. The overall dimensions of the probe are 5 × 0.8 × 1.7 in.

Preprocessing and Interface Circuits

To provide ample tolerance for mistracking (±.675 in for typewriter size) and a 5:1 range of acceptable print sizes, the Cognodictor probe has a field of view of 1.5 in. About 1,500 photocells sense this space so the vertical resolution is nearly as much as the lens quality will allow. Horizontal resolution is about 333 samples/inch.

The preprocessing circuits utilize two numbers (a tracking number and a lumping number) produced by either the user or the computer to determine which photocells are over the desired line and to combine samples from these cells to yield a standard height for the electronic letter image transmitted to the computer. The horizontal

samples are combined in the same proportion (given by the lumping number) as the vertical samples (photocells) to yield a width which is appropriate for the letter height. When the combining process has been completed, the interface circuits interrupt the computer and the computer accepts four 16-bit words (64 bits which comprise one column of points in its internal letter image). These preprocessing and interface circuits were assembled on two plug-in circuit boards each 4½ X 6½ in. They use 47 integrated circuits of the low power Schottky TTL family.

Cognodictor Software Development

During July 1976, a systems analyst, Dr. Chung C. Lee, began writing and testing computer routines which will eventually be combined into a large program which simulates almost all of the Cognodictor's functions. When sufficiently perfected, this program will form the basis for the Cognodictor software. Also, in July, a test input-output routine was written. In August, the development of a video display program was started. This display program causes the cathode ray tube to display the contents of the input buffer area of the computer's memory consisting of 1,024 words, of 16 bits each, which form images of the last 10-12 characters scanned by the probe. (Before the two interface boards between the photocell development board and the PDP-11 computer were operating, this buffer area contained synthetically produced letter shapes which were entered by hand.) The program also draws five horizontal lines delineating the boundaries between the four 16-bit words which comprise each column of points in the display.

The display routine, an initialization routine and an interface input routine were completed and debugged during September and October. Test signals were provided by the photocell array which scanned print attached to a constantly rotating drum. The interface circuits were operating except for the substitution of a fixed frequency clock pulse for the optical encoder signal.

In November 1976, three computer routines were written. The first one locates the left-hand and right-hand edges of the next character to be recognized and also yields a measure of its width. The second routine then locates the upper and lower edges and determines character height. Considering the rectangle whose sides coincide with these four edges as the character space, the third routine checks each inside corner of that space for black. The results of checking four corners yield 16 combinations of results.

During December 1976, the recognition routines which had been written to date were tested, using the hand-held probe to scan several hundred lowercase letters. The printout produced indicated

that the routines operated as intended. In January 1977 the next group of routines was completed. These routines will detect a vertical or nearly vertical straight line near the left or near the right edge of the character and will measure the length of each such line found. During February 1977, a number of routines needed for specific tests in the recognition of lower case o, c, e, a, s, and t were developed.

FUTURE WORK

Prototype Construction

Still to be assembled are the two circuit boards needed for the speech synthesis portion of the prototype. It appears that the printed circuit board which was designed to hold 16 programmable read-only memory circuits (PROMs) for the previous Cognodictor can be used for the PROMs which will contain the speech synthesis program. A new circuit board will be needed for the 8080 microprocessor, read-write memory, input-output ports, and associated circuits. Perhaps a suitable board can be purchased; if not, designing one should not be difficult.

Dr. Scott Allen at NIH has been writing a new version of the speech synthesis program we have been using. If the new version is available it can be loaded into the PROMs: if not, the older program can be used until a better one is available; at that time, the PROMs can be erased and reprogramed. The compact speech synthesis system consists of two circuit boards (each 6.5 in × 4.5 in) and a Votrax VS-6 (11.5 × 11.5 × 3 in).

It will be necessary to purchase the LSI-11 components for the recognition portion of the prototype. Thus far, a readymade plug-compatible PROM board for the LSI-11 has not been found and it may be necessary to prepare artwork and have a local circuit board manufacturer make several such boards (existing commercial PROM boards use fusible link PROMs which cannot be reused).

Software Development

The design of the optical probe, and the choice of an LSI-11 microcomputer for the recognition portion of the Cognodictor, provide a basis for performance which will be determined mainly by software. At present, the software capabilities are limited mainly by the time and manpower available for its design.

The first version of the recognition routines includes only the basic routines for recognizing uppercase and lowercase letters (excluding italics). Punctuation and numeral recognition are to be

added in Version 2. Separation of touching characters would be a main feature of Version 3. Automatic line-following and automatic adjustment of type size are probable additions to Version 4. Later versions can add routines for recognition of italic fonts, and routines which operate an automatic page-scanner. Each version should also contain modifications which improve earlier routines, as user experience reveals the need for such improvements.

Prototype Evaluation

It is expected that Mr. Harvey Lauer at VA Hospital, Hines, Illinois, will be the first outside user of the High Performance Cognodictor prototype. Mr. Lauer is already skilled in probe manipulation and in using the aural direct-translation output code. It is hoped that previously unskilled potential users of the Cognodictor, such as veterans being rehabilitated at Hines, will receive exposure to the Cognodictor and some training in its use and that the feedback from these individuals will be available to the designers. After about 8 months the prototype could be moved to another situation (such as a business office, school, or home) for additional testing.

Other Developments

When the effort required to maintain and improve the Cognodictor software and hardware diminishes, work could begin on the design of an automatic page scanner accessory. Both the basic design of the device and its interface with the operator require thorough study. For example, the operator controls might be either a specialized keyboard with keys for different functions, or a standard full keyboard as on a typewriter (with single letters or mnemonic combinations of letters as the control codes) or a "joystick" controller with a few auxiliary pushbuttons and controls.

Perhaps the choice should be influenced by possible future extensions of the Cognodictor's capabilities. Some of these possibilities are:

1. With the standard keyboard and additional software the Cognodictor could become a talking intelligent remote terminal for a bigger computer, or it could be a stand-alone minicomputer if a mass storage device such as a floppy disk unit is added.

2. With the above peripherals and a hard copy output such as a Selectric printer, the performance of a magnetic card typewriter could be duplicated. Other input-output combinations are possible, utilizing braille line printers, paper tape readers, or telephone line connections.

3. The speech generation components (8080 microcomputer and Votrax) could be used separately as part of a Teletype replacement for blind programers or workers such as reservation clerks, who interact with a computer.

In conclusion, it may be a waste of an expensive prosthetic appliance to utilize the power of the microcomputers and the voice synthesizer in the Cognodictor only for reading—if other functions can be added as options at reasonable costs. This possibility should be studied in detail.

A DESCRIPTION OF THE KURZWEIL READING MACHINE AND A STATUS REPORT ON ITS TESTING AND DISSEMINATION

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ABSTRACT

This paper presents a technical overview of the different subsystems of the Kurzweil Reading Machine—the nature of the information processed by each subsystem and the type of transformations performed. A description of how the user directs the machine is provided. The Veterans Administration's testing program, as well as those of the Bureau of Education for the Handicapped, the Rehabilitation Services Administration, and the National Federation of the Blind, are outlined.

Preliminary tests of the machine with blind secondary school students have focused on the intelligibility of the synthetic speech output, and the results of these tests are presented.

INTRODUCTION

The Kurzweil Reading Machine converts print to speech, and is designed as a reading prosthetic aid for the blind and visually handicapped. The system handles ordinary printed material—books, letters, reports, memoranda, etc., in most common styles and sizes of type. The output produced is a synthetic voice using full-word English speech.

The user operates the device by placing printed material face down on the glass plate which forms the top surface of the scanning unit; he then presses the "Page" button on the control panel, and listens to the synthetic speech produced as an electronic camera

scans the page and transmits its image to a minicomputer housed within the device (Figs. 1, 2, and 3). The computer separates the image into discrete character forms, recognizes the letters, groups the letters into words, computes the pronunciation of each word, and then produces the speech sounds associated with each phoneme.

The machine operates at normal speech rates, about 150 words per minute.

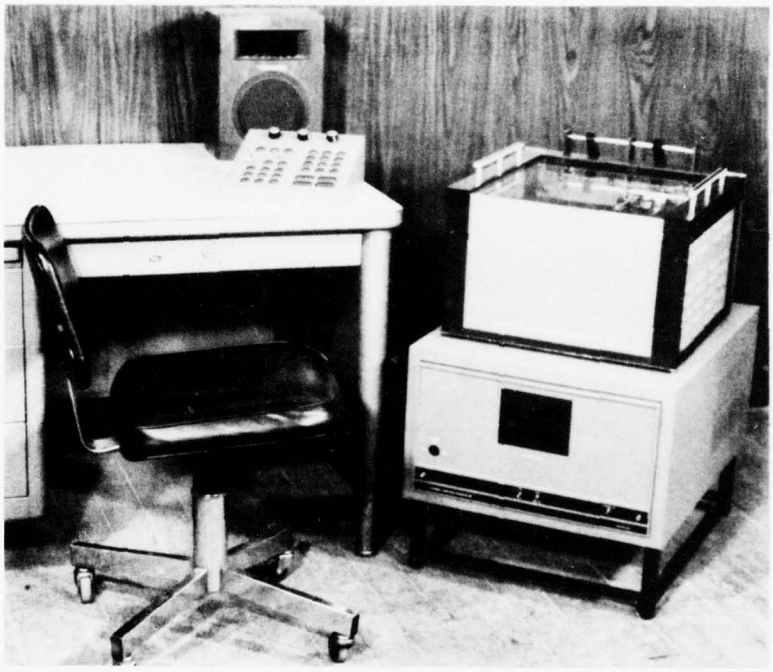

FIGURE 1.—Kurzweil Reading Machine for the Blind. On the desk are the loudspeaker and the user's control panel, and to the right the glass-topped scanner which has been placed on top of the electronic unit.

THE SUBSYSTEMS

The Scanner

The first subsystem of interest is the scanner. A high-contrast electronic image of the page to be read is generated by the scanner, which includes a linear photosensor array at the focal plane of a

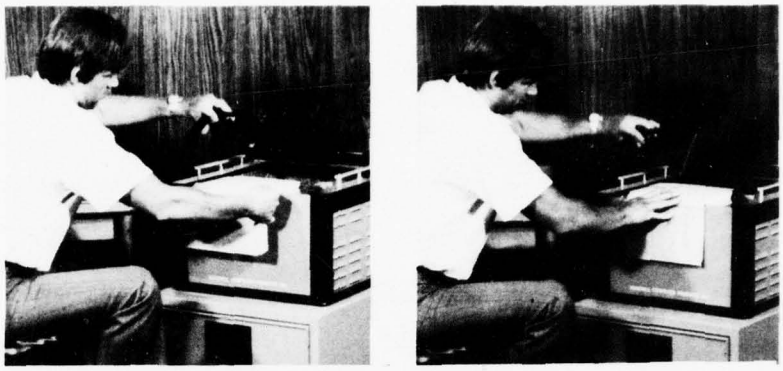

FIGURE 2.—Adjusting a book for reading on the Kurzweil Reading Machine.

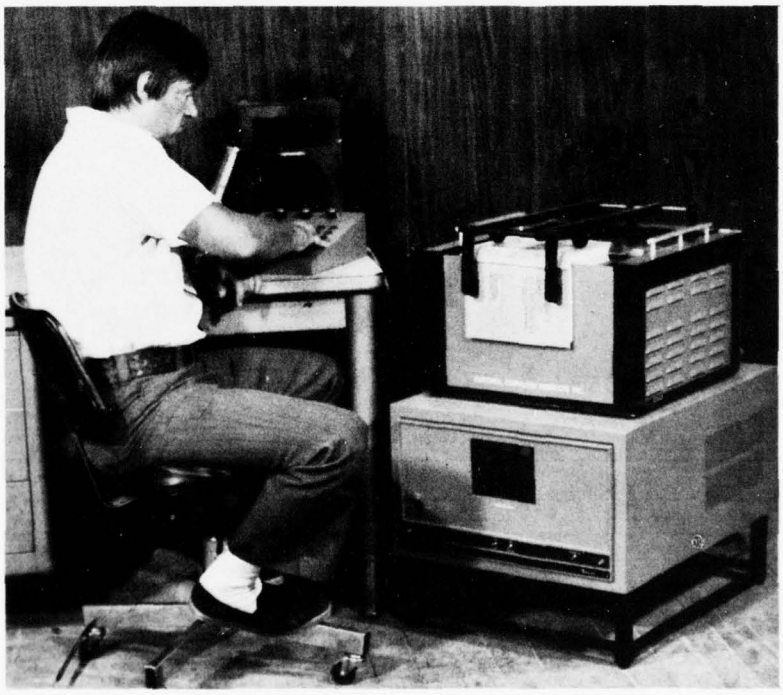

FIGURE 3.—User operating controls to read a book mounted on the Kurzweil Reading Machine scanner.

camera mounted on an X-Y mover. The text page is placed face-down on a glass plate above the X-Y mover, which moves the camera in a plane parallel to the plane of the text. The photosensor array is perpendicular to the direction of text lines; thus, a single scan across a page results in an electronic image covering a strip of the page which includes several text lines.

Immediately after the user presses the "Page" button, the scanner moves to the limit of its travel in the direction of the top of the page, and begins to search for the first text line. When the first line is found, the camera tracks that line and moves automatically down to the following lines, tracking each in turn. Scanner efficiency is maximized by scanning left-to-right and also right-to-left; material scanned right-to-left is reversed by the computer before the output stage.

Character Recognition

Scanner output, which can be imagined as a simple two-dimensional matrix of black and white points, is processed by the character recognition system, beginning with the isolation of each contiguous area of print in the page image. Each contiguous print area is presumed to be a single character, with the exception of certain special cases requiring additional processing; e.g., touching or fragmented characters, and dots associated with particular characters. Each individual character is analyzed by a set of feature extraction routines. The features, or properties, extracted are those that have been found to be relatively invariant for the same character with respect to the kinds of changes that occur across different typestyles. These properties are basically geometric—line segments, concavities, loops, loop extensions, and the positional relationships among these elements. For example, the properties of a standard capital "A" include a single loop and a single south-facing concavity. Once the properties have been extracted, they are compared to stored lists describing each character in the identification set. (Examples of characters outside the identification set, that is, characters not presently identified, include various special mathematical symbols, and non-Latin alphabets.)

The output of this process is usually a final identification, although it is occasionally an ambiguity code indicating one of several possible final identifications based on contextual cues. In this case, the final identification is made by a special module (called the "disambiguator") which analyzes positional and other contextual cues to "disambiguate" the output of the shape recognizer. An example is a single vertical bar. The shape recognizer output will indicate that this shape is the lower-case letter "i" if there exists a dot above

the character, or the lower-case letter "l" if there exists no dot and the character is in a letter context, or the number "one" if there exists no dot and the character is in a number context. (A character is in "number context" generally if it is adjacent to a number.)

The final step in character recognition is text line formation—that is, the collation of individual characters into words and punctuation to be analyzed by the speech generation system.

Speech Generation

The primary function of the speech generation system is to determine the proper pronunciation of each word; i.e., grapheme strings are converted to phoneme strings. This is accomplished by a set of over 1,000 phonetic rules supplemented by a dictionary of exceptional cases. First, prefixes and suffixes are stripped off by algorithms which reconstruct the root—for example, "Rating" is converted to "rate"-"ing." The exception dictionary is checked for the resulting root, and if the root has been entered into the dictionary, the dictionary phonemes are used. Otherwise, the root is passed to the phonetic rules module. Whether the rules module or the exception dictionary is used, the prefix and suffix, if any, are looked up in a special affix dictionary and properly appended to the root phoneme string.

Stress marks, which are modifiers tied to each phoneme in the form of relative pitch and volume parameters, are also generated by the exception dictionary and the phonetic rules for intra-word stress-assignment. A stress contour over each sentence, for improved prosody, is computed by a set of primitive syntactical rules that look primarily for certain lexical cues indicating cutoff phrase boundaries. These rules range from the very simple:

> If a word ends in a question mark or exclamation point, stress it. (This generally gives the appropriate stress pattern to questions and exclamatory sentences.)

to the more complex:

> Relative pronouns are stressed if the *preceding* word was not a relative pronoun ("that which is . . .").

Rules of the second type utilize an internal dictionary of syntactic types, entirely distinct from the phonetic exception dictionary.

The final step in speech generation is a conversion of the phoneme string into the speech waveform. This operation is performed by a hardware synthesizer, which is essentially a set of variable electronic filters designed to model the human vocal tract. Synthe-

sizer output is amplified and transmitted to a speaker—and the machine "talks."

User Controls

For everyone, sighted or blind, reading is properly an active rather than passive process; one re-reads interesting or difficult passages, pauses at unfamiliar words, skims the page to find material of particular interest, and so on. The Kurzweil Reading Machine allows its user to interact actively with the text he is reading via the user controls, which are a set of keyboard-mounted buttons. When the "Page" button is pressed, the scanner automatically finds the first line of text on the page and begins reading, continuing down the page until the "Pause" button is pressed, at which point the scanner (and the speech output) is halted. When "Resume Scan" is pressed, output is resumed at the current scanning position.

After "Pause" is pressed, and until "Page" or "Resume Scan" is pressed, the machine is in "pause mode." While in pause mode, the user may utilize buttons to manipulate the reading machine in several ways. He may read a single line or a single word, repeating as often as he wishes, and he may move forward through the text in line or word increments; he may have words spelled out rather than normally pronounced.

If the user presses "Set Mark," the computer will note the current scanner position; if at a later time he presses "Go To Mark" the scanner will return to the "Set Mark" position. Using a keyed numeric input in conjunction with the mark facility allows the user to mark, and return to, several different positions.

This is only an overview of the control options available to the user; our keyboard presently includes 30 buttons. The physical configuration, however, is designed to allow the novice user easy access to the five or ten buttons most important to his reading. Still, the favorite button of many inexperienced users will probably be the "Nominator" key; if that key is pressed immediately preceding the pressing of any other key, the machine will not perform the command associated with the second key, but rather will tell the user its function (by speaking the name of the key).

ANTI-OBSOLESCENCE STRATEGY

An important design goal was to produce a high-performance (rapid, easy to use) reading machine for the blind which would not become obsolete. With continuing rapid advances in digital component fabrication techniques, the problem of a design becoming obsolete by the time it is completed is a serious one. Therefore, we

have implemented any information-handling process likely to change, in software. The software can and will be modified over time as the system continues to be shaken down, and as further improvements are implemented. Software changes, as they are developed, can be distributed to units in the field in the form of software update tapes, which can be loaded into each reading machine using the digital cassette tape drive provided with each unit. In this way, even the first set of reading machines will be able to take advantage of improvements such as the development of other languages. Special character sets (mathematical symbols, for example) can also be introduced to units in the field using special cassette tapes, again without requiring hardware modification.

A final advantage is that for future production runs we can take advantage of more efficient components—new microCPU's, new memory chips—as they are introduced, without having to redesign the heart of our technology, which is primarily in software.

HISTORY AND CURRENT STATUS

The project began approximately 10 years ago. After approximately 5 years of feasibility study, algorithm simulation, component review, and other preliminary steps, Kurzwell Computer Products was organized to implement a fully working model. About 1½ years ago (Fall 1975), the first system capable of scanning a printed page in multiple type styles and converting it to comprehensible full-word speech was completed. The current system is now the fifth version of the Print-to-Speech system.

The machine was demonstrated last summer (1976) at the national convention of the National Federation of the Blind in Los Angeles, at the national convention of the Blinded Veterans Association in Philadelphia, and more recently in Washington at the Bureau of Education for the Handicapped and before the Senate Subcommittee for the Handicapped.

While the initial development of the reading machine has been completed, further improvements are possible. Reading is a complex activity. Print specifications differ significantly among printed documents, varying in the style and size of type, the grade of paper and ink, the quality of printing, and the page format. The purpose of reading may also vary, ranging from skimming to intensive study. Extensive user experiences in the field will enable us to optimize the machine's ability to handle the largest possible diversity of reading situations.

To guide this continuing refinement, feedback is currently being collected under several programs from those who will be affected

by the machine; blind children and adults, teachers, and rehabilitation professionals.

Veterans Administration Program

The Veterans Administration Program will test the reading machine with blinded veterans, and will seek to improve the device based on the reading needs of this population. An initial placement will be made at the Central Rehabilitation Section for Visually Impaired and Blinded Veterans, at VAH, Hines, Illinois.

The National Blinded Veterans Association has endorsed the VA's purchase of the machine and its clinical evaluation. Jerry Monroe, the BVA national president, has been particularly helpful in providing guidance, enthusiasm, and insightful user input for the project.

The short-range goal of the work at Hines is to evaluate the usefulness of the machine in its present state for purchase by the VA for the various blind centers as a teaching and experimental tool. The long-range goal is to establish the ultimate usefulness of the machine at its eventual market price, for blind and visually-impaired persons. The first step in this project will be an examination of the performance and functioning of the machine by Harvey Lauer and others. Then the following areas will be explored:

1. Interaction with the world of print—the percentage of character-recognition accuracy as a function of type style, page format, and printing quality.
2. The control interface—the machine's provision for interaction with the user will be examined, and the aptitude and training requirements will be described.
3. The output interface—the intelligibility rate of the synthesized speech output as a function of character-recognition accuracy rates, pronunciation error rates, pace of output, intelligence of user, length of user experience with the machine, etc., will be described. The ultimate effect of these variables on reading and comprehension rates will be described.
4. Finally, the Kurzweil machine will be compared with other modes of reading—braille, recordings, sighted readers, other reading devices. The machine's applicability to the needs of blinded veterans will be tested, and the VA's 30 years of pioneering experience in the development and evaluation of reading machines for the blind will be utilized in this effort to apply new technology to the needs of blind people.

Other Federal Programs

The machine is also being evaluated under a program with the

Department of Health, Education, and Welfare (HEW) which includes tests sponsored by the Bureau of Education for the Handicapped (BEH) and the Rehabilitation Services Administration (RSA), both in that department.

The BEH program is focusing on the use of the reading machine in educational situations, particularly with school-age blind children. Data are being collected concerning the use of the machine, and the machine will be improved on the basis of this feedback from blind children, their parents, and their teachers. The first placement under the BEH program was made in the fall of 1976, at the Perkins School for the Blind in Watertown, Massachusetts.

The RSA program will focus on the use of the reading machine by blind adults in vocational situations and will provide feedback from blind consumers and rehabilitation specialists. The first RSA placement will be made shortly at the West Virginia Rehabilitation Center. Additional placements will then be made at Arkansas Enterprises for the Blind, and the Iowa Commission for the Blind.

NFB Participation in Development

In addition to the Federal evaluation programs, a comprehensive human engineering consumer-based study of the reading machine has been organized in collaboration with the National Federation of the Blind.

The National Federation of the Blind is the largest organization of blind people and has for the last 3 years advised the company on the development of the machine. As part of the current study, the Federation is placing six reading machines in a variety of user situations—in the office of a blind executive, a lawyer, an engineer or scientist, in a rehabilitation center, and so on. On the basis of this experience and suggestions that result from use of the machine, the Federation will provide guidance on ways in which the machine can be made more responsive to the needs of blind readers through such things as additional user controls and improved physical configuration.

The program has been designed, and is being implemented and directed, by the NFB's own scientists and engineers.

The funds for this program, incorporating a new concept of consumer involvement in the design process, have been contributed by five major foundations across the country. Initial testing of the reading machine by Michael B. Hingson of the NFB's staff began several months ago in Boston.

We believe it is important for designers and consumers to involve each other in this kind of intensive way, and thus increase the relevance and quality of new technology for the disabled.

Preliminary Tests on Secondary School Children

In the preliminary tests of the machine conducted under the BEH and RSA programs, seven secondary school students whose only disability was visual impairment and who were of normal intelligence, were subjects for this initial study. The study was structured as a comparison of the subjects' performances in decoding (understanding single words in isolation) and comprehending (understanding paragraph-length material) the reading machine's synthetic speech.

The Durrell Listening-Reading Series, Advanced Level (for grades 7-9) was selected as the test instrument. Four sets of wordlists and paragraph-length passages, each of equal level of difficulty, interest value, and representativeness of vocabulary sample were presented to each student as follows: (i) test using human speech; (ii) test using synthesized speech—subjects had no previous exposure to synthetic speech; (iii) test using synthesized speech after moderate practice; and (iv) test using synthesized speech after more extensive practice.

Due to limitations, no student received more than 3 hours total exposure to the synthetic speech before testing ended. Briefly, the results of the tests were as follows (using the mean scores for the subjects):

The highest scores were obtained using natural human speech—9.83 for word repetition and 12.00 on paragraph comprehension;

The lowest scores were obtained upon first exposure to the synthetic speech—4.83 for word repetition and 9.50 on paragraph comprehension;

The scores for final tests using synthesized speech were most encouraging—9.37 for word repetition and 11.17 on paragraph meaning.

Given the limited sample size, there is no statistically significant difference between the human speech scores and the final synthetic speech scores. Later studies will utilize larger and more diverse population samples, as well as more extensive test material, but the results obtained from this preliminary study agree with the experience of nearly everyone who has practiced with the reading machine—it is not difficult to comprehend the synthetic speech after only a few hours of exposure.

A PRELIMINARY FOLLOWUP STUDY OF ELECTRONIC TRAVEL AID USERS

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INTRODUCTION

The history of electronic travel aids (ETAs) for blind travelers is not lengthy, particularly the period of commercial availability. However, during these few years there have been many modifications to the aids and to methods of instructing potential users. The C-5 Laser Cane has replaced the C-4 Laser Cane and the Sonicguide is today's name for the Binaural Sensory Aid, while the training of Orientation and Mobility Specialists has been refined and systematized with university-based ETA programs. Training methods have been improved as a result of these programs and the accumulation of experience and research in the use of the devices. Yet there remain many areas in which a paucity of accessible information exists.

For example, given the variety of ETAs and the many potential users, how does one match an aid with an individual? What factors should be considered? How is an aid integrated (or not integrated) into a user's lifestyle? In general these questions have not been answered because the primary focus of effort has been on developing useable aids and delivery of those aids to potential users—with little emphasis on the longer-term consequences.

Since 1971 the Western Blind Rehabilitation Center (WBRC) has participated in delivery of ETAs to selected veterans. During this time 26 veterans have been trained with, and issued, either a Laser Cane or Sonicguide, and a much larger number have been evaluated

for the aids.[a] By early 1976 the paucity of information on the outcome of issuance of ETAs to veterans had come to be recognized as a severe limitation to continued progress in the development of an effective ETA program. This inability to provide staff members with feedback on the consequences of their clinical training program imposed the following critical limitations:

1. Without feedback information, validations of current training practices could not be made.
2. Without feedback information, the likelihood that a given training program will expand into new and promising areas of endeavor is reduced.
3. Without feedback information, the enthusiasm and forcefulness of training personnel will wane, and this will eventually limit the efficacy of the training itself.

These consequences were recognized by the Western Blind Rehabilitation Center, and the method described here for providing feedback from trained ETA user to instructor was initiated. The authors hope that this is only the first of a series of information-gathering studies. This paper presents the results of only the initial effort—the preliminary nature of this report is emphasized.

METHOD

Subjects

Of the 26 veterans who had been trained with an ETA at the WBRC by the time of this study, 18 were included in the data analysis. The remaining 8 individuals were not included because 3 of them had moved to a different geographical area and the 5 others were known not to use the ETA issued to them.[b] Of the

[a] Evaluation was primarily in terms of the individual's physical, mental, and psychological ability to use one of the aids, and the apparent strength of motivation. Obviously if the kind of data discussed in the preceding paragraph were available, the evaluation process could be improved.

[b] Veterans known at the outset of the study to have discontinued their use of the aid were not included as Followup Study subjects. However, during the study's direct observation phase it became apparent that 10 of the 18 subjects had also either discontinued use of the aid or no longer used it as intended. This fact should be borne in mind when considering data based on the original group of subjects. Where it seemed appropriate, the authors provide data drawn only from the 8 subjects found to be still effectively using their aids at the time of the study.

It should also be noted here that, for some subjects, their aid had apparently fulfilled important rehabilitative functions while they were achieving independent mobility, after which these users no longer felt a need for the equipment. With this later insight it becomes apparent that the Preliminary Followup Study proved more fruitful than might have been the case had the authors been able to identify—and exclude at the outset—that majority of their subjects who turned out to be discontinued users of the aids.

18 subjects selected 12 had received the Sonicguide and 6 had received the Laser Cane. While these two groups are hardly matched samples they are in many respects similar. The mean age of the Sonicguide group was 48.2 years versus 46.2 years for the Laser Cane group. The mean educational levels (defined simply as number of years of formal education) were also similar with the Sonic group having a mean of 13.7 years versus 15.0 for the Laser Cane group. Mean number of years blind was 15.2 for the Sonic group and 15.1 years for the Laser Cane group.

The mean length of time the Sonicguide users had had their aid was 2.3 years (range = 1 to 4 years), while the mean for the Laser Cane users was 3.5 years (range = 2 to 5 years). All users reported traveling independently on a daily basis, although not always with an ETA.

All subjects had received ETA training at the Western Blind Rehabilitation Center. Prior Orientation and Mobility Training had occurred either at one of the three VA Blind Rehabilitation Centers or an outside agency. (Outside agencies had provided O&M training for about one out of four of the subjects.) In all cases, if remedial work on mobility skills was needed by a subject prior to ETA training, the additional training had been provided at the WBRC.

Phone, then Visit

Initial contact was made with each subject by telephone. The interviewer first explained the study to the veteran and asked him to participate. Then the interviewer asked a number of questions about prior mobility training, use of the aid, and the individual's travel patterns on the day immediately prior to the telephone call. In this way information that would be useful for the on-site visit was obtained. All veterans reached by phone expressed interest and were willing to participate.

On-site visits in the veterans' homes were made within a few weeks of the initial telephone contact by one of the authors (Nancy Darling). The visits served to provide objective, comparable information about the veterans' mobility and ETA skills. In particular the on-site visits provided a means of observing and assessing the veterans' mobility skills within the actual home environments. In each case, direct observations were made in an area immediately surrounding the veteran's residence, and where appropriate, observations were also conducted at the veteran's place of employment.

FINDINGS

Travel Patterns

All subjects had stated that they traveled "independently." However, observations indicated wide variation in what constituted independent travel. Two subjects, for example, appeared to have travel patterns dependent upon other persons (as in a car-pool) rather than relying only upon their own travel skills. Others appeared to have travel patterns solely dependent upon their own travel skills. All subjects appeared to be capable of relying upon themselves, if required to in travel situations, by employing a long cane, an ETA, or a dog guide.

The majority of both groups (7 of the 11 Sonicguide subjects responding to the question and 3 of 5 Laser Cane subjects responding) indicated their amount of travel had increased since receiving ETA training. The remainder indicated their amount of travel was about the same. None indicated a decreased amount of travel.

Table 1 presents the data on the kinds of areas the subjects reported traveling in, while Table 2 presents the subjects' reasons for traveling. Ten in the Sonicguide group and 6 in the Laser Cane group responded to these questions. Although the total number of subjects is small, the data may provide a useful hint of several differences between the two groups: it suggests that Laser Cane users are more likely to use their ETA indoors than are Sonicguide users, while the latter are more likely to report using the ETA in residential and/or urban areas.

The Sonicguide users appeared to be more likely to begin traveling in new areas than did members of the Laser Cane group. Some in the Sonicguide group also reported fatigue or distraction while none in the Laser Cane group did.

TABLE 1—*Areas Reported Traveled in by 10 Sonicguide Users and 6 Laser Cane Users*[a]

	Sonicguide		Laser Cane	
Area	Number	Percent	Number	Percent
Residential	8	80%	3	50%
Light business	6	60%	3	50%
Urban	5	50%	1	17%
Public transportation	5	50%	3	50%
Indoor	3	30%	4	67%
Other (School campus, home yard)	3	30%	1	17%
Rural	1	10%	1	17%

[a]Only five veterans actually used their Sonicguides and three actually used their Laser Canes at the time they answered this inquiry.

TABLE 2—*Reasons Reported for Traveling by 10 Sonicguide Users and 6 Laser Cane Users*[a]

	Sonicguide		Laser Cane	
Reason	Number	Percent	Number	Percent
Exercise	6	60%	3	50%
Job/School	5	50%	4	67%
Errands	5	50%	3	50%
Other	7	70%	3	50%

[a]Only five veterans actually used their Sonicguides and three actually used their Laser Canes at the time they answered this inquiry.

Family Opinion of ETA

During the followup visit family members were asked to describe their opinions of the ETA by placing it within a category of positive, indifferent, or negative. Family members of Sonicguide users usually rated their feelings as positive (7 to 9 responding) with one indifferent and one negative. Only 1 of 4 responding family members of Laser Cane users stated a positive opinion, while 2 were indifferent and 1 was negative. These responses may be the result of factors independent of the ETA, such as perceived need to defend the user. One comment made by some family members to justify their negative feelings was that the ETA made the user "too independent."

Mechanical Functioning

Of 11 responding Sonicguide users 4 reported having had mechanical problems with their aid, while all Laser Cane users reported some malfunction. (Mechanical problems were defined as repairs being necessary for proper ETA functionings.) To assess the relative rate of malfunctions over time, the total number of months all aids had been in the hands of the subjects was divided by the total number of malfunctions reported. From this calculation the malfunction rate for the Sonicguide appears to be once per 5-year period, and for the Laser Cane about once per 6-month period.

Use of the ETA Observed

Sonicguide Subjects

During observations of the ETA users it appeared that only 5 of the Sonicguide subjects were using the aid effectively (e.g., responding to its signals). The remaining 7 individuals had either returned their aid to the Veterans Administration, or did not demonstrate an ability to use the aid, which probably indicated a lack of practice

(and hence a disuse of the aid). Of those who had returned the Sonicguide, several noted that the aid had been effective but because of a change in location or lifestyle the aid was no longer useful to them. For example, a travel area was no longer one in which use of the aid seemed appropriate or helpful.

Laser Cane Subjects

Of the 6 Laser Cane users observed, it appeared that only 3 were using the aid effectively at the time of the followup. The remaining 3 could not demonstrate effective use of the aid.

Data From Telephone Interviews

Both groups reported traveling similar amounts of time (per day) with their aids. The 5 Sonicguide users' reports averaged 31 minutes travel time per day and the 3 Laser Cane reports averaged 37 minutes. The average distance traveled was, however, slightly longer for the 3 Laser Cane users, whose travel averaged 7.5 city blocks. The Sonicguide users' travel averaged 5.5 city blocks.

The specific types of items located by the users with an ETA are listed in Table 3. (Table 3 and 4 report only those users the authors could confirm as using the ETA.) The Laser Cane group reported using their aid for locating objects in their travel path more frequently than did the Sonicguide group. The Sonicguide users, however, made more frequent reports of using the aid to detect landmarks or hazards (head-height objects) than did the Laser Cane users.

TABLE 3—*Items Reported Located with ETA by 5 Sonicguide Users and 3 Laser Cane Users*[a]

	Sonicguide		Laser Cane	
Item	Number	Percent	Number	Percent
Hazards (head-height)	5	100%	2	67%
Objects (in travel path)	4	80%	3	100%
Landmarks	3	67%	2	67%
Other (parked cars, better line of travel)	2	40%	0	0%

[a]The authors were able to confirm use of the aids by these subjects.

Table 4 presents the aid(s) used on the day prior to the telephone interview as reported by the Sonicguide and Laser Cane subjects themselves. The Sonicguide users appeared more likely to use a long cane (without the ETA) and/or a sighted guide than to use their ETA.

TABLE 4—*Aid Reported Used on the Day Prior to Telephone Interview by 5 Sonicguide Users and 3 Laser Cane Users*[a]

Aid	Sonicguide		Laser Cane	
	Number	Percent	Number	Percent
Sonicguide	2	40%	–	–
Laser Cane	–	–	1	33%
Long Cane	4	80%	2	67%
Sighted Guide	2	40%	0	0%
Guide Dog	1	20%	0	0%

[a]The authors were able to confirm use of the aids by these subjects.

DISCUSSION

The major focus of attention on electronic travel aids has historically concerned the development of the devices, their distribution to prospective users, and the development of training curricula. Less attention has been given to validating these processes in terms of the long range interaction between an ETA and a user's life patterns.

The National Academy of Sciences' evaluation of the C-4 Laser Cane (1973) provided some information concerning use of the Laser Cane during training and for a limited period of time following training. The study concluded (in part) that the Laser Cane was *most effective in two situations*—first, "in moderate density urban traffic along familiar routes" and second, "in unfamiliar urban areas with low traffic density." The present study supports the latter conclusion since Laser Cane users reported frequent use of the cane in light business areas. However, in comparison to the Sonicguide, the Laser Cane does not appear to be most effective in urban areas.

The NAS study also concluded that the Laser Cane was not effective in conditions such as building interiors, high density (noisy) traffic conditions, or in crowded corridors. In the present study the Laser Cane users did not commonly report using the aid in crowded areas; they did, however, report more frequent use of the Laser Cane indoors than did the Sonicguide users.

In agreement with the NAS study was the finding that Laser Cane users and Sonicguide users were both more likely to rate their own travel ability higher than would a trained observer. The present subjects rated themselves as exceptional travelers.

The present study also elicited reports (from users) that their travel frequency increased following ETA training. This finding may be in conflict with the NAS study finding that Laser Cane use did not increase travel frequency. However, since direct observations of

travel frequency were not made in the present study it is possible that the finding represents only the users' belief, and not an actual increase in travel frequency.

Airasian (1972) conducted a questionnaire survey of Binaural Sensory Aid (Sonicguide) users and instructors from the United States, England, Australia, and New Zealand. The questionnaire was designed to obtain information on user characteristics, training, mobility skills before and after ETA training, mechanical adequacy of the device, and attitudes toward training and use of the device. Because of differing methodologies (e.g., questionnaire versus on-site visit) and subject populations (e.g., non-veteran versus veterans and congenital versus adventitiously blinded) direct comparisons between the present study and Airasian's are hazardous. Some differences are apparent: in particular, Airasian reports that 79 percent of the users retained their aid, while the present study concludes that 44 percent retained their aid and could use it effectively. Such disparities suggest a need for further research to determine retention and use patterns within defined populations.

The Patterns of Use and Disuse

Those veterans trained with an ETA but no longer using it were questioned to obtain information on why they chose not to use the aid. A principal reason reported was a change in home, business, or school location such that the aid was no longer felt to be effective (or necessary) to meet the new mobility situation. For example, the previous situation may have required extensive or complex travel, while the new situation either did not require sufficient travel or involved travel in an environment not suited to the aid. In these cases it may be postulated that a subsequent change would lead the veteran to resume using the aid—although no evidence currently exists to support or refute this position.

A second reason cited for discontinuing use of the aid was that the individual (through use of the ETA) became so familiar with his environment, or so confident of his travel ability in that environment, that the aid did not add to his travel ability and was therefore no longer used. In these cases the users cited the aid as necessary and useful during initial familiarization with the environment. At a later time the ETA's output became too redundant to warrant continued use.

Other users reported opposite reactions. For example, one individual continued using the aid in familiar environments and employed it to "explore" his travel route. He gained a great deal of enjoyment from the aid as an environmental sensor—while only infrequently employing it as a mobility aid.

When asked about the areas traveled with their ETA, Sonicguide users were more likely to report utilizing the ETA in urban areas than were Laser Cane users, while the latter more frequently reported using their ETA inside buildings. Due to the small population these results are not suitable for statistical analysis, but they are at least suggestive of a differential application of the two aids. If subsequent research confirms such differentiation it may eventually be possible to match one or the other aid to certain users on the basis of travel patterns. Such matching might be thought of as analogous to the prescribing of low-vision aids, wherein many aids will provide a user with better visual acuity but only one aid (or one system of aids) will allow him to achieve optimum performance in a particular task he must perform.

In conclusion, the study found that 8 of the 18 veterans participating in the study continued to use their ETA and were able to demonstrate effective performance with it. The remaining veterans either could not demonstrate effective use of the aid or had returned the aid to the Veterans Administration. Among those no longer employing the aid, a frequent statement was to the effect that the aid had initially been very helpful, but due to changes in environment, self-confidence, knowledge of the environment (gained with the help of the ETA) or other factors, the aid was no longer employed. These findings indicate that the importance of the ETA is greater than that reflected in a 44-percent use rate.

On the basis of these findings the following recommendations are made:

1. Followup studies should become integral parts of all ETA programs. The purpose of these studies should include evaluation of current training programs as well as evaluation of user performance variables.
2. Additional research should compare use patterns of the Sonicguide with those of the Laser Cane to determine if they are in fact differentially employed by users, and to determine if such differentiation is a valid guideline for prescribing Sonicguides or Laser Canes to prospective users.
3. The present study found ETAs to be of relatively short-term use to many users; however, despite the short duration, the impact of the aid was evident. Thus, consideration should be given to applying ETAs, in some instances, as an orientation tool with the goal of improving initial mobility training and initial adjustment to mobility within the user's environment. The explicit agreement between the instructor (representing the agency) and the client would be that the use of the ETA is for a limited period of time and is intended only as a supple-

ment to orientation and mobility training.

4. This concept of the use of ETAs as a supplement to normal orientation and mobility training should receive appropriate research attention. An example: the use of the Laser Cane's auditory output as a secondary source of reinforcement in teaching the concept of hand centering and arc width in the use of the long cane.
5. Additional guidelines need to be developed and validated for optimum selection of ETA candidates.
6. The possibility of employing ETA's to improve poor mobility skills should be explored.

ACKNOWLEDGMENTS

Many individuals aided the authors in the development of this paper, the veterans who participated, and most of all the Mobility Section from the WBRC. We benefited greatly from the counsel of Bill Ekstrom, Mark Voorhies, Rex Ward, Ron Fenchak, Stan Paul, and Phil Syverson. Mr. Howard Freiberger and Eugene F. Murphy, Ph. D., were instrumental in initiating the ETC program at the WBRC and have continued to provide support, encouragement, and words of wisdom.

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VETERANS ADMINISTRATION PROSTHETICS CENTER RESEARCH REPORT

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I. DEVELOPMENT AND EVALUATION

A. Prosthetics

1. *Lower Limb*

a. *Graphite-Epoxy Composite Components.* To date we have been unable to develop a knee joint of this material for below-knee

prostheses due to difficulties in shaping this composite material and due to its brittleness. We are continuing our effort to develop the graphite-epoxy SACH foot keel; Hosmer/Dorrance Corporation was awarded a VA contract to produce 20 pairs of SACH feet with graphite-epoxy keels as cores. These were produced in shoe sizes 6½ and 7 for both right and left amputees. These SACH feet met VAPC standards and are being sent to selected field stations for further evaluation.

b. *Polypropylene Hip Joint and Pelvic Band.* This system, described in BPR 10-25 and BPR 10-26, has been reported by patients to be lighter, more comfortable while ambulating and sitting, and more durable, than other systems. This device is now commercially available to all prosthetic facilities from U.S. Manufacturing Co.

c. *DAW Stump Sock System.* DAW Industries of Minneapolis, Minnesota, has manufactured a stump sock system for amputees that has been called "the perfect system." The system uses a nylon sheath, a wool (3 or 5 ply) sock, and a laundry bag. The sheath and sock can be machine-washed-and-dried with the use of the laundry bag.

The DAW Stump Sock System was fitted to 15 unilateral and bilateral above- and below-knee amputees who had previously worn wool stump socks. According to wearers the socks reduced abrasions, minimized perspiration, and provided a more intimate fit than conventional stump socks. The nylon sheath, however, developed runs or tears after a short time, apparently from being pulled too hard during donning. The DAW Stump Sock System is commercially available from the manufacturers in all sizes for above- and below-knee amputees.

d. *UC-BL Four-Bar Polycentric Knee.* Preliminary evaluation of a prototype four-bar polycentric knee mechanism developed by the Biomechanics Laboratory, University of California at Berkeley, has shown that the device offers improved knee function. Because of its polycentric design, knee stability is improved and the flexion range of the knee is increased. A pneumatic unit added to the basic mechanism controls swing phase. The UC-BL four-bar linkage knee is modular, and includes: (i) an adjustable socket alignment coupling of the spherical type allowing a range of ± 5 deg in adduction, abduction, flexion, and extension, plus unlimited axial rotation; (ii) a knee unit with plastic knee cap; (iii) shank pylon tubing; (iv) internal expanding tube couplings, and (v) a SACH foot attachment. Standard stock cosmetic covers were used.

Wearers found that walking with this prosthesis was easier, more secure, and less tiring than with devices with which they were familiar.

B. Spinal-Cord-Injury Rehabilitation

1. *Environmental Control Systems*

a. *Prentke Romich ECU 1.* This system (Fig. 1 and 2) manufactured and distributed by the Prentke Romich Co., Shreve, Ohio, provides 12 channels: four are 120-V a.c. standard power outlets and eight are 12-V d.c. outlets for remote switching systems. The standard power outlets are used to supply power to television sets, radios, and lamps. The 12-V d.c. outlets, two of which are controlled by internal latching circuits (the momentary switch simply sets or resets these circuits), are used to control various battery-operated devices, tape recorders, intercoms and other nurse-call devices, page turners, electric beds, and (in remote operations) standard power receptacles or outlets. A separate built-in relay is included for two additional simple switching operations.

Control signals are displayed on the ECU Input Display, whose 14 indicator lamps correspond to the 14 functions of the unit. A flexible gooseneck is used to hold the control switch.

Nine of these systems are being evaluated. Evaluation is not yet complete, but early results have been favorable.

b. *Voice-Operated Typewriter and Environmental Control System.* This device (VOTECS), described in the Spring 1975 edition of the Bulletin (BPR 10-23, pp. 246-248), was developed by Scope Electronics, Inc., Reston, Virginia. It has three modes of operation: (i) training the VOTECS to respond to each user's vocabulary and voice pattern, (ii) allowing functions to be performed, or the system's typewriter keys to be activated, through spoken commands, and (iii) providing for retraining of command words as required.

The VOTECS under clinical evaluation at VAH, Richmond, Virginia, for nearly 2 yr has operated well for most of this time. It has demonstrated that voice recognition as a control means can be used successfully by certain persons with quadriplegia to type and operate electric appliances through an added environmental control system. Because of its maintenance requirements, cost, and limited application it should be considered for patient use only after extensive consideration of all other options, and of the requirements of its use.

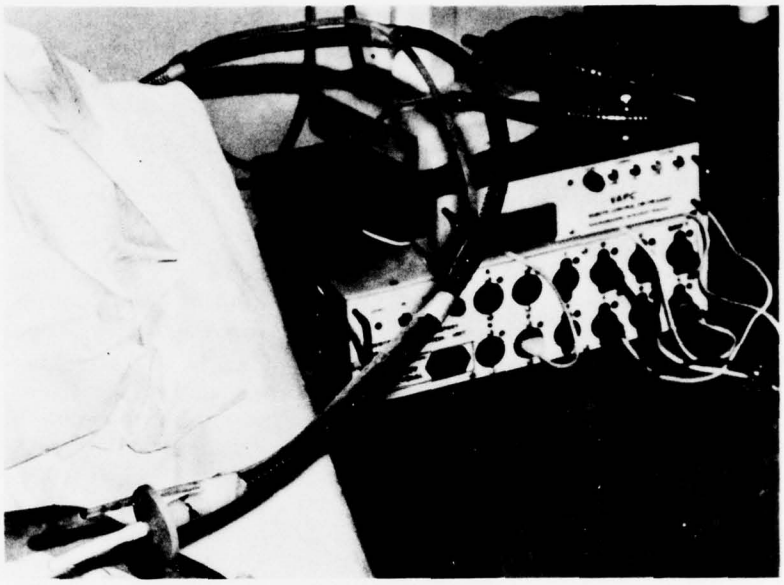

FIGURE 1. (above)—Prentke Romich ECU 1 (Environmental Control Unit) offers 12 channels plus two simple switching operations. Flexible gooseneck keeps control switch accessible to patient.

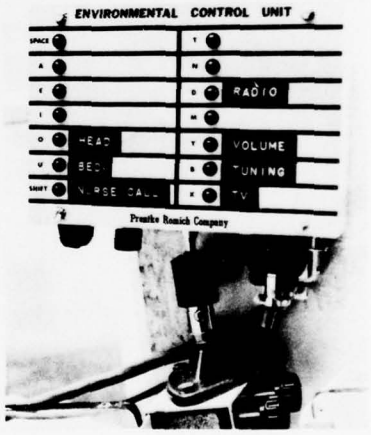

FIGURE 2. (right)—Prentke Romich ECU 1 input display shows control signals on 14 indicator lamps which correspond to the 14 functions of the unit.

c. *Touch-Operated Selector Control.* This system (TOSC) is described in the Bulletin of Prosthetics Research (BPR 10-26). One system, installed in a veteran's home, developed an early malfunction but has functioned well for several months. The patient finds the TOSC system very useful for such routine activities as dictating his comments for phone calls for the day, or for recording incoming

phone calls. Also, the intercom has allowed him to communicate with members of his family in other parts of the house.

He feels the system is excellent for himself, or for others with similar functional ability.

d. *Fidelity Comfort and Communication Control System.* This system (FCCS), described in BPR 10-23 and BPR 10-26, was developed by the Northwestern University Rehabilitation Engineering Program and is manufactured by Fidelity Electronics Ltd., Chicago, Illinois. It is a solid-state environmental control system with eight functions that allow a quadriplegic to independently operate up to eight electrical appliances by using one of two available types of controls: a hand-operated (either wired or wireless) pushbutton control, or a pneumatic control.

Seven FCCS systems, installed in the homes of disabled veterans, were evaluated. Advantages cited by the patients are that the system is compact and packaged in a woodgrain box that blended well with home furnishings. The eight available functions are ideal for the average spinal-cord-injured patient. The remote control feature is well conceived and of great utility.

e. *Fidelity Comfort and Communication System Security Sentinel.* The Fidelity Comfort and Communication System (FCCS) Security Sentinel developed and distributed by Fidelity Electronics, Ltd., Chicago, Illinois, is an environmental control system that provides disabled persons with the means to respond to potentially dangerous home situations.

The system provides five security and safety functions—a closed circuit television monitor to observe and identify front entrance callers; a wired intercom to communicate with a front-entrance caller; an electric pneumatically controlled door-lock release; a heat-and-smoke detector that monitors the presence of unusually intense heat or smoke and activates an automatic telephone dialer (or an audible alarm) when necessary; and an automatic emergency telephone dialer. When activated by the heat-and-smoke detector, the dialer automatically dials a prerecorded number (e.g., the local fire department) and provides recorded emergency information (i.e., location, etc.).

Twelve units have been in use in the homes of 12 veteran beneficiaries for several months. All units have functioned well. Comments from the patients indicated that installation was easily accomplished and that the system has been highly useful.

The television surveillance of the area outside the front door, and the intercom system, provide a general sense of security to the

homebound veteran. It is recommended that this device be made available to qualified veteran beneficiaries on prescription when used in conjunction with the Fidelity Comfort and Communication System (FCCS).

2. *Communications Aids*

a. *Manual Communications Module.* The MCM Communication System (Fig. 3) is designed and marketed by Silent Communications, Inc., Oakland, California. The system consists of a portable electronic typewriter designed to interface with ordinary telephones through a built-in acoustic coupler. It provides a convenient means for deaf and other hearing-impaired persons to communicate through the telephone and the Phone-Teletype network. Clinical evaluation was conducted by the Prosthetic and Sensory Aids Service, VA Outpatient Clinic, Baltimore, Maryland. As a result of the information obtained from the clinical evaluation, it is recommended that the MCM Communication System be made available for eligible veterans on prescription.

b. *Portable Telephones*

Two portable (no wire) telephone systems are currently being evaluated.

These systems free the telephone instrument from the need to be connected by wire to the regular telephone circuit. They have

FIGURE 3.—Manual Communication Module showing portable electronic typewriter with built-in acoustic coupler, and scroll cassette unit.

an extra base or relay unit which plugs into the telephone company's wire circuit, and this unit relays the message to and from the instrument via low-power radio broadcasting. The phone instrument itself must also have low-power radio receiving and sending capabilities to complete the link.

Handicapped persons living independently may rely heavily on the telephone as a means of calling for advice or help in an emergency. The radio-equipped telephone allows them to have a phone continuously at hand as they move from room to room, in the workshop or garage or while taking a bath, or out at poolside, etc. The system can also be moved to a summer residence, motel, etc.

The systems currently being evaluated are—

(1) *Kari-Fone* (Fig. 4 and 5). This wireless portable telephone, available from the Kari-Fone Corp., Elmhurst, New York, is an FM

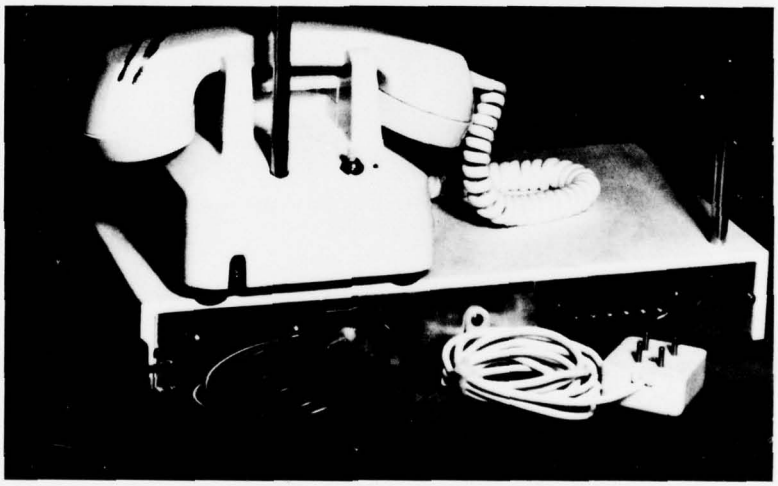

FIGURE 4. (above)—Kari-Fone (rear view) with battery charger. Terminal block at right is intended to permit handling up to five different telephone numbers on a single base unit.

FIGURE 5. (right)—Kari-Fone portable telephone, front view, with instrument resting on base relay unit.

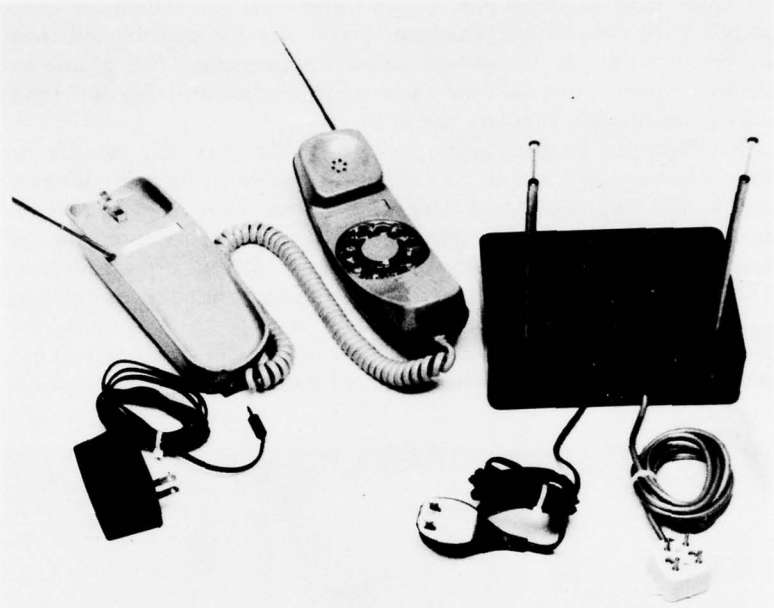

FIGURE 6.—PortaCall portable telephone instrument and base units, with telephone plug and battery charger. Note telescoping antennas.

radio device. The manufacturer claims that Kari-Fone complies with FCC regulations and does not require licenses or permits. There is a single telescoping antenna on the base portion of the instrument (none on the hand-held portion) and one on the relay unit. There is also a fixed internal antenna.

(2) *PortaCall* (Fig. 6). This wireless portable telephone is an AM radio device. The manufacturer claims advantages similar to those claimed for Kari-Fone. It has two telescoping antennas on the relay unit and one on each portion of the instrument itself.

c. *Mechanically Operated Voice Synthesizer.* This system (MOVS), designed and manufactured by Scope Electronics, Inc., Reston, Virginia, is now under evaluation. The MOVS is a vocal communication aid for persons with speech impairments. It produces an electronically synthesized voice output that consists of mechanically selected combinations of phonemes, words or phrases that are listed on a data tablet. A 32-character readout is supplied to display the vocabulary combinations chosen prior to the de-

livery of the message. The (Votrax) voice synthesizer, the voice controller (computer), and a speaker, process and deliver the spoken message. The voice synthesizer, voice controller, and data tablet control are mounted in a movable chassis.

d. *Lifeline System.* This automatic home emergency-alarm system (Fig. 7) developed at Boston University, is manufactured by Lifeline Systems, Inc., Newton Centre, Massachusetts. It automatically dials a telephone during an emergency, transmitting a message to a central station which initiates a response. A receiver and digital printer, both manufactured by Security Sciences of America, Scottsdale, Arizona, are located in the central station.

The Lifeline System can be actuated by any one of three different procedures: by the patient using manual switches located in strategic areas of his home; by the patient using a portable RF trigger; and by an automatic monitor that calls for help when the patient is presumed to be incapacitated. The monitor or timer (which can be set for from 1 to 24 h) is reset by the patient's use of the telephone (or by his simply lifting the handset). Should the timer not be reset, which might indicate that the person is incapacitated, it first sends a warning signal to the patient, and if still not reset, sends an automatic call for outside help.

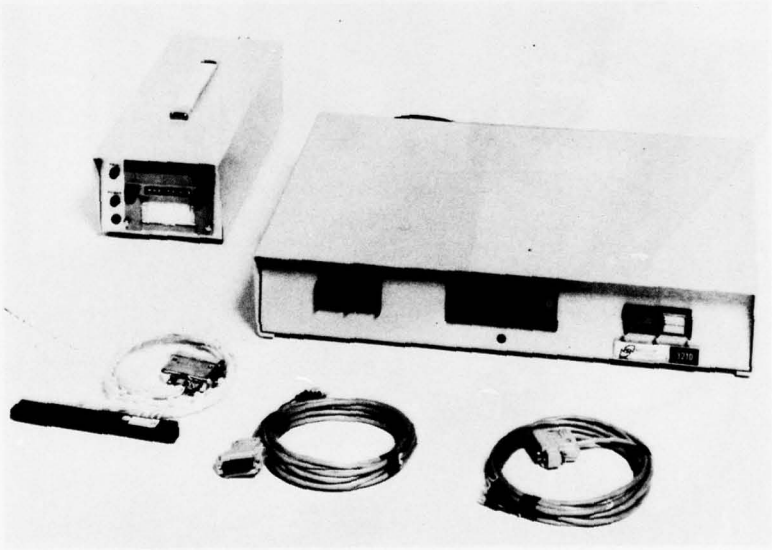

FIGURE 7.—Lifeline System, an automatic home emergency-alarm system.

While the Lifeline System functioned according to design, it required a number of people and a central-station answering service for implementation of the appropriate reaction by the appropriate agency. Other systems serve the same purpose with fewer requirements. The manufacturer is willing to set up a central-station answering service if a "significant need" exists.

e. *New Ealing Reader.* This is an automatic scroll-reading device (Fig. 8) for the physically handicapped, developed by the Ealing Corp., South Natick, Massachusetts. The reader is portable and may be clamped on the over-the-bed table included in the package, or on any table. Operating power is supplied either by an internal rechargeable battery or any standard 115-V a.c. source.

The New Ealing Reader consists of a main frame, a scroll cassette, a full tape on a spool, a take-up spool, and three control switches. The main frame contains the drive system, a rechargeable battery, printed-circuit control boards, and the receptacle for the cassette.

The New Ealing Reader has been undergoing clinical trials at VAH Spinal Cord Injury Services in the Bronx and at Castle Point

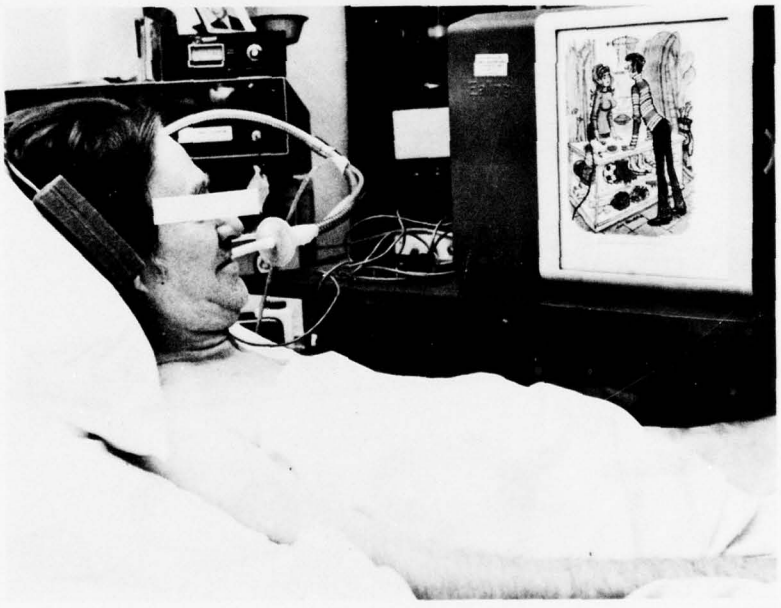

FIGURE 8.—New Ealing Reader in use.

and Brockton. One unit was modified by the company to operate pneumatically, and a Rehabilitation Engineer modified another for use as an accessory on an environmental control system. A magnifier was attached to one unit for patients with visual problems.

Comments from patients and staff indicated some difficulty in setting up the apparatus, but it was very easy to operate thereafter. Questions arose concerning copies of reading material required,

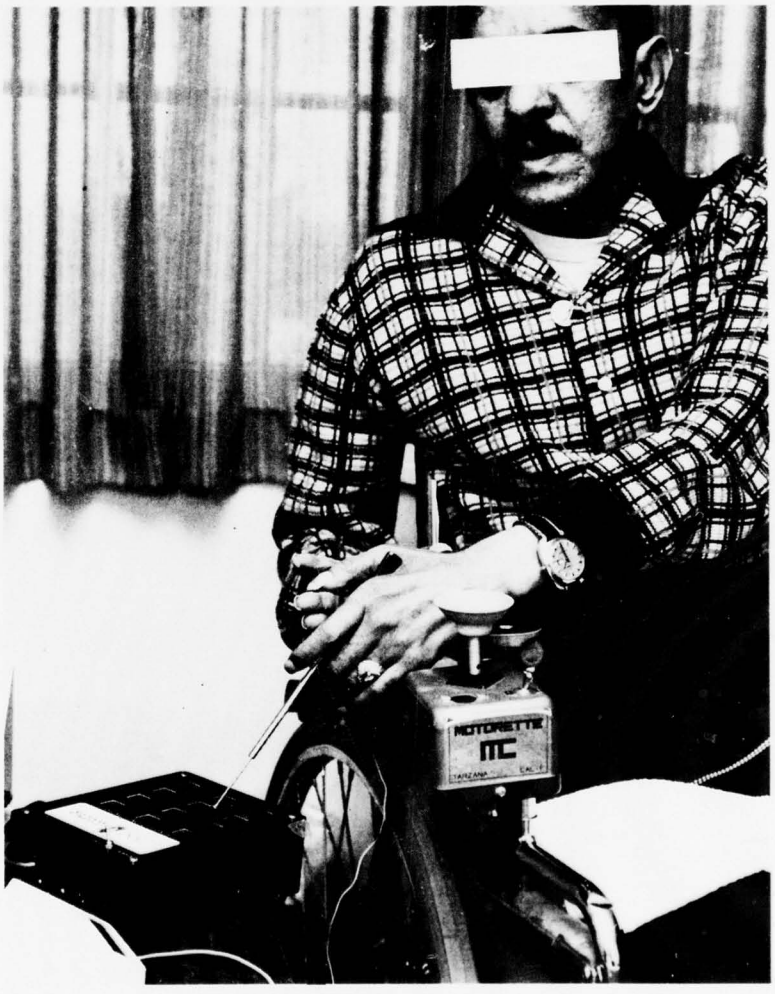

FIGURE 9.—Zero-Pressure Telephone Dialer in use.

storage space needed to store spools . . . and the fact that the daily newspapers did not fit into the device.

f. *Zero-Pressure Telephone Dialer.* The dialer, (Fig. 9), manufactured by Med-i-electric and distributed by Medical Equipment Distributors, Inc., Upper Darby, Pennsylvania, is a touch-operated telephone for persons with limited or no hand function. The system is activated through skin contact on the surface plate above the numbers, or by using the special tip of the MED mouthstick that is provided by the manufacturer. The Zero-Pressure Telephone Dialer is being evaluated in the home of a disabled veteran.

g. *Sip "N" Puff Dialer.* This dialer (Fig. 10) is manufactured by Med-i-electric and distributed by Medical Equipment Distributors, Inc., Upper Darby, Penn. It is a breath-controlled telephone dialer designed to be operated by a high level quadriplegic. The unit is installed by connecting a telephone extension into the Sip "N" Puff unit's receptacle. The Sip "N" Puff unit is then plugged into the telephone wall outlet. The phone receiver is mounted on a flexible arm, which is then clamped to a convenient table.

The user puffs lightly on the tube to get a dial tone and then sips on the tube to create a vacuum. Holding the vacuum with his

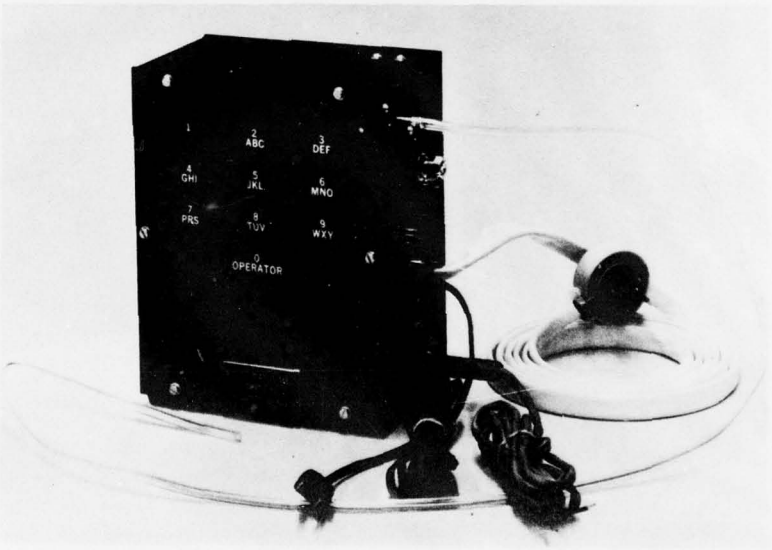

FIGURE 10.—Sip "N" Puff Dialer.

tongue over the end of the tube, the user waits until the number he wishes to dial appears in the display. He selects the number by releasing the vacuum and repeats the cycle for sequentially presented numbers. When the telephone conversation is completed, the user simply puffs on the tube to "hang-up" the receiver.

The device is still being evaluated.

h. *Microlert System.* Developed by the Microlert Corp., North Hollywood, California, this electronic alert system operates through the telephone network. When activated, the system automatically summons assistance through pre-selected calls.

The system consists of a wrist-worn RF micro-transmitter, an RF receiver, and a base station. Depressing the pushbutton located on the wrist unit transmits a signal to the receiver located strategically in the house. The receiver then simultaneously activates an automatic telephone communicator and an audible alarm. If the device is not deactivated, a series of pre-recorded taped emergency numbers are automatically dialed and pre-recorded messages are delivered. The tape cassette is pre-recorded by the company using a special recorder.

The Microlert System is presently being clinically evaluated.

3. *Mobility Aids*

a. *Rigal Walker Tray.* This device (Fig. 11), invented by Mr. Waldo Rigal, of Mount Pulaski, Illinois, is a folding walker that in-

FIGURE 11.–Rigal Walker/Tray.

corporates a folding tray. It is designed to assist persons to stand and walk. An attached tray provides a level surface for carrying small objects. The device did not comply with VA specifications in laboratory tests.

b. *VAPC Pneumatic Wheelchair Control, Model II.* The VAPC Pneumatic Wheelchair Control Model II, a dual-tube, momentary controller with an experimental third tube to vary wheelchair power and speed, is being evaluated. The control has been modified to relate motor power in the forward mode to the magnitude of positive intraoral pressure. In response to higher positive pressure in either or both pneumatic tubes, motor power increases proportionately. Negative pressure causes either or both motors to operate in reverse at a consistent low-power level.

Speed is varied through two pneumatic linear potentiometers (Fig. 12) which regulate the power output of pulse-width-modulated, d.c. motor controllers. Maximum power to a drive motor is achieved when 0.25 psi is developed within the corresponding pressure transducer.

An Everest & Jennings "32" Power Drive 24-V wheelchair (Fig. 13) is equipped with this system.

c. *Electrically Operated Brake for Powered Wheelchairs.* The VAPC has initiated a program to develop an effective braking system that would preclude undesired wheelchair motion (of either powered or conventional wheelchairs) in the event of control

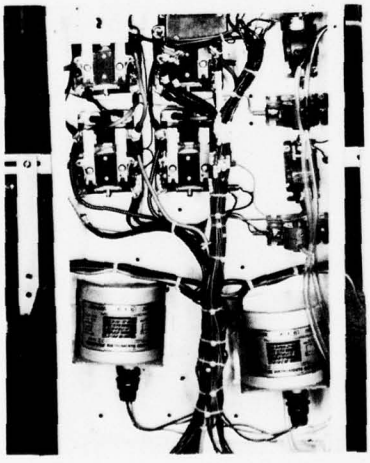

FIGURE 12.—VAPC Pneumatic Wheelchair Control Model II. Inside view of proportional control unit showing pair of pressure transducers (pneumatic linear potentiometers).

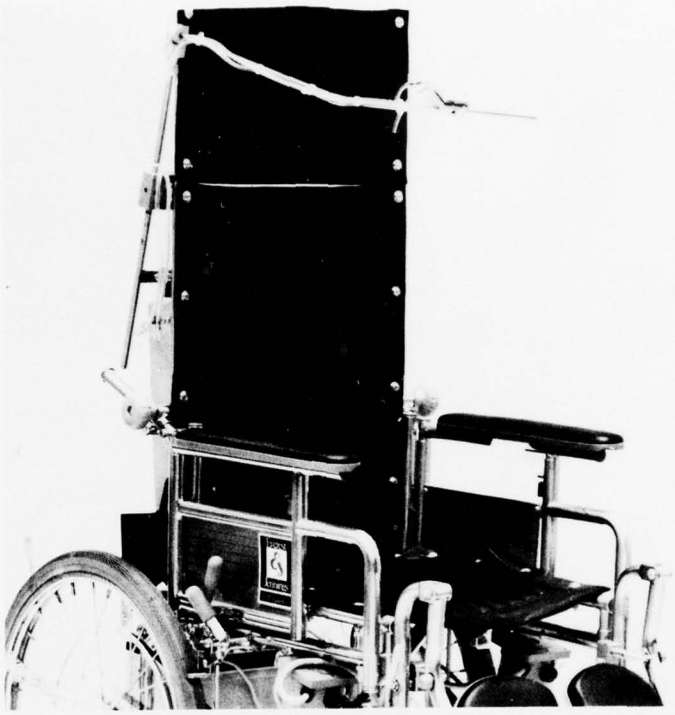

FIGURE 13.—VAPC Proportional Pneumatic Control on wheelchair: this control system superficially resembles the Model II Control which has dual tubes.

failure or power drive failure, and when the wheelchair is parked on an incline.

Two units are under evaluation. One, employing a caliper concept, is mounted on a wheelchair driven by a Photocircuits Power Wheel (motorized hub) system. A second unit (Fig. 14) is mounted on a chin-controlled Everest & Jennings "33" electric wheelchair.

d. *Icarus Easy Transfer Wheelchair Attachment.* This device (Fig. 15), manufactured by Icarus Health Aids Ltd., Netanya, Israel, is a transfer board that is permanently attached to a wheelchair. It is currently being tested.

e. *Amigo Motorized Wheelchair.* This wheelchair (Fig. 16) is a commercially available tri-wheeled motorized wheelchair manufactured by Amigo, Inc., Bridgeport, Michigan. It is designed for

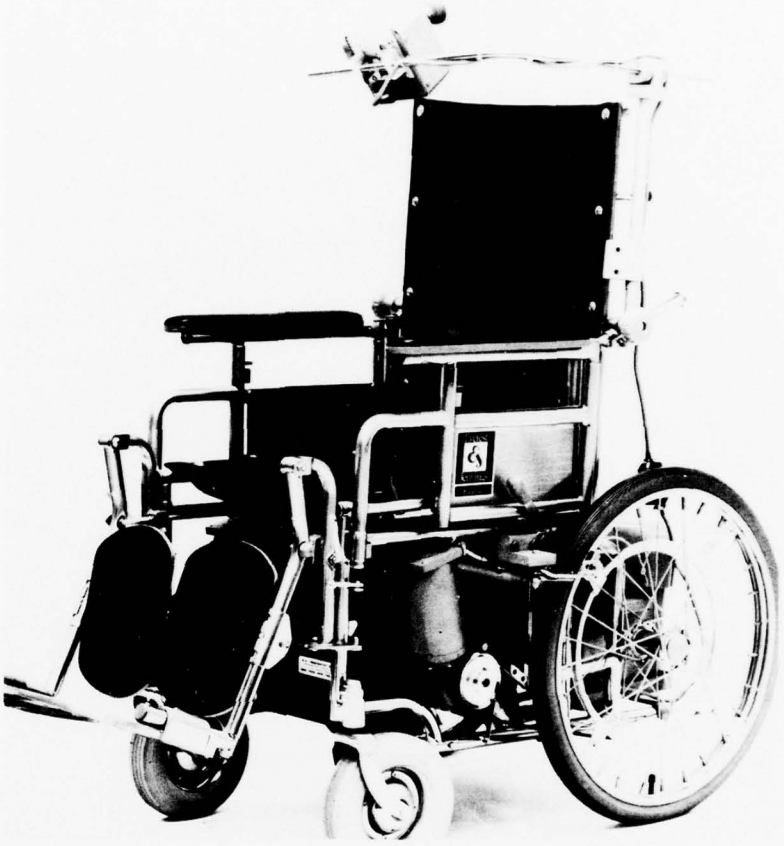

FIGURE 14.—This E&J "33" electric wheelchair has been equipped with one of the electrically operated brake systems currently being evaluated.

persons who have upper-body control but who fatigue easily, such as arthritic and geriatric patients, and persons with cardiovascular problems, emphysema, polio, and multiple sclerosis.

Two units were evaluated. They were found mechanically and structurally adequate and met standards for electrical safety. However, it is difficult to determine precise medical indication for prescription. It is being recommended for use by veterans when prescribed by a physician.

f. *Invacare Elite Series 800 Wheelchair.* The Invacare Elite Series 800 Wheelchair is manufactured and marketed by the Inva-

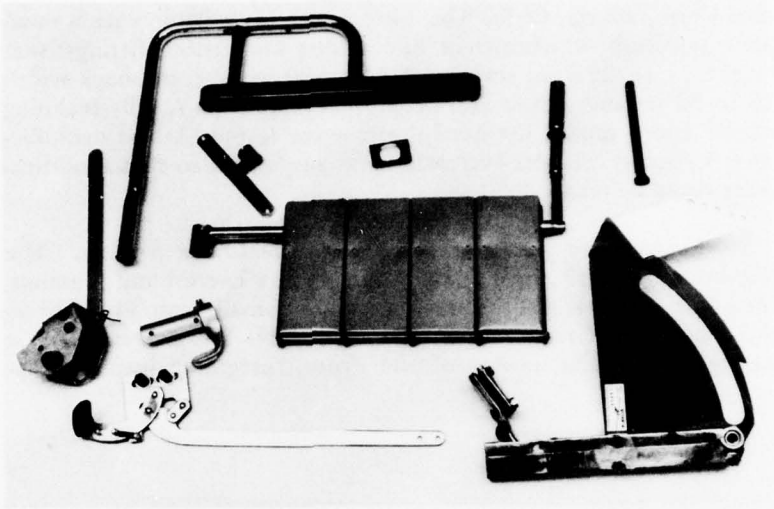

FIGURE 15.–Icarus Easy Transfer wheelchair attachments.

FIGURE 16.–Amigo tri-wheel motorized wheelchair..

care Corp., Elyria, Ohio. The Elite series is available with a complete selection of wheelchair dimensions for custom fittings: seat height 17 to 22.5 in; seat depth 13 to 20 in; seat and back width 16 to 22 in; and seat-to-arm height 7.5 to 13.5 in. A fully reclining model and a model for hemiplegics were tested. At the manufacturer's request, clinical evaluation was suspended so that modifications could be made.

g. *Everest and Jennings Hub-Brake Wheel-Lock System.* The hub-brake (Fig. 17 and 18), manufactured by Everest and Jennings, Inc., Los Angeles, California, consists of a small drum attached to the wheelchair's rear vertical frame support. The rear-wheel axle passes through the center of the drum. Integrated into the rear

FIGURE 17.—Everest and Jennings Hub-Brake Wheel-Lock System installed on a wheelchair. The brake rod may be connected to the lever to produce a push-to-lock or a pull-to-lock action, as desired.

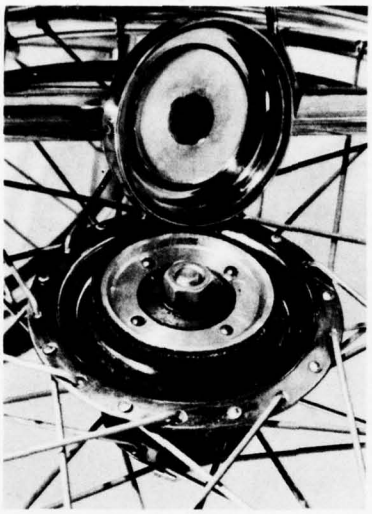

FIGURE 18.—Everest and Jennings Hub-Brake Wheel-Lock System.

wheel is the brake's rocking plate and brake lining. Either pushing or pulling of the brake lever can be used to force the brake lining against the brake drum: Push-to-lock or pull-to-lock lever-action is selected by simply removing the nut that attached the brake rod to the lever, and repositioning the rod in the desired hole. The rod is secured by replacing the nut to complete the conversion process.

h. *Everest and Jennings Rehabilitation Shower/Commode Wheelchair.* This device manufactured by Everest and Jennings, Los Angeles, California (Fig. 19), is currently being evaluated. It is designed to assist non-ambulatory and other individuals in shower bathing and/or commode use for personal hygiene.

4. *Body Support System*

Castor Portable Standing Frame. This device, manufactured by Arthur L. Castor, Inc., Compton, California, employs bilateral vertical axillary supports to provide the means whereby a low-level-lesion quadriplegic or paraplegic is able to achieve and maintain an erect standing position for improved renal function, calcium retention, and strengthening of functional musculature through an exercise regime in the erect position (Fig. 20). One unit is being evaluated.

5. *Lifts and Transfer Aids*

a. *Mobilizer.* The Mobilizer is a powered patient-transfer de-

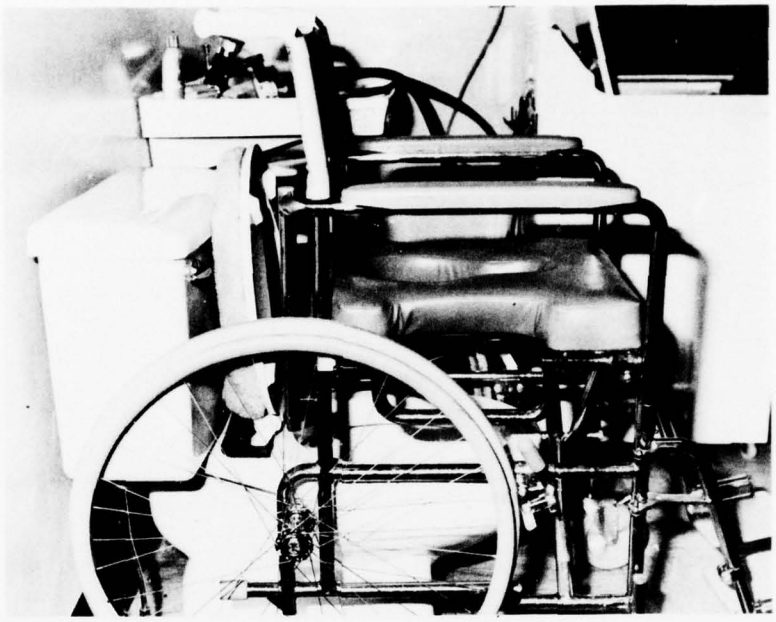

FIGURE 19.—Everest and Jennings rehabilitation shower commode wheelchair.

vice manufactured by the Diamondhead Corp., Mountainside, New Jersey. As previously described in the Spring 1974 edition of the Bulletin (BPR 10-21, pp. 100-101), this unique device features a supporting surface, and a transfer surface which extends out laterally from the device itself and slips under the patient, transporting him from one surface to another. With this device, one attendant can transfer patients gently, safely, and economically without lifting or touching the patient in any manner. This unit features a hand-held remote control box that allows one attendant to transfer a supine patient to and from a bed or treatment table, and to raise or lower the transfer surface of the device 16 in. to approximate the heights of beds or tables. Power is supplied by a 24-V storage battery with built-in charger. The unit has removable side rails, and is mounted on four 10-in. casters for transporting patients to other areas by pushing or pulling (not powered).

The Mobilizer was clinically evaluated at various VA Hospital Spinal-Cord-Injury Centers throughout the country. It was found to be easy to operate, maneuverable, comfortable, safe, and quite useful. It is recommended that the Mobilizer be made available to VA Hospital Spinal-Cord-Injury Centers.

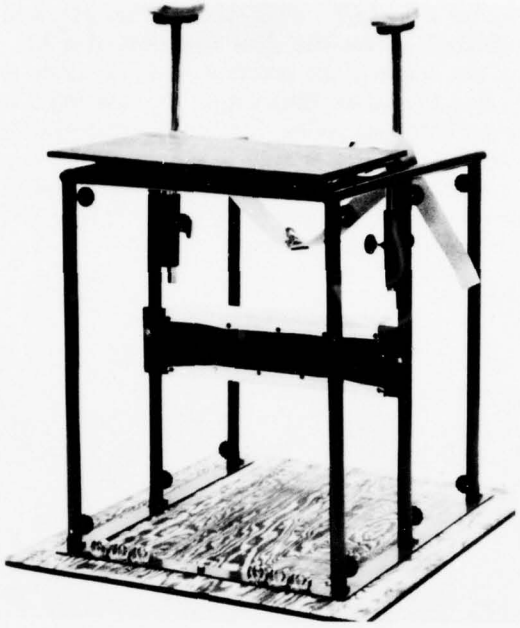

FIGURE 20.–Castor portable standing frame.

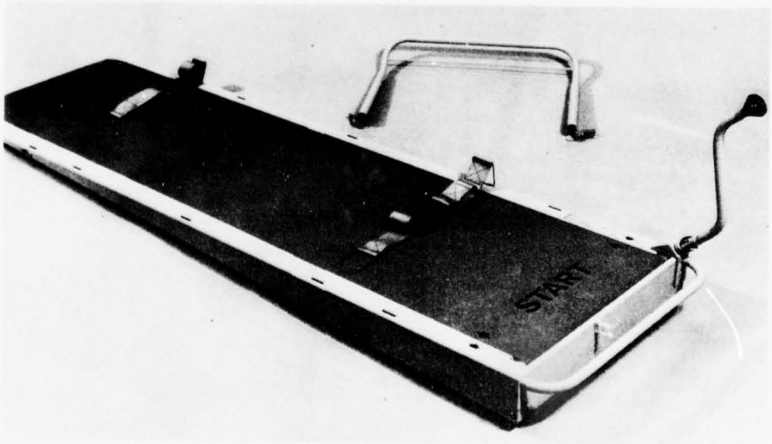

FIGURE 21.–Duphar Life Lift can serve as both lift and stretcher. Crank handle at right produces motion of surface to bring patient aboard without manual lifting and little or no movement of patient's spine. Safety straps are used to secure patient for carrying.

b. *Duphar Life Lift.* This device (Fig. 21), which is currently being evaluated, serves the dual function of a lift and a stretcher for use at the scene of an accident. It is available through Medical Methods, Bay St. Louis, Mississippi. By rotating a revolving handle that moves a series of rollers located beneath the resting surface of the device, the operator is able to eliminate the need for manually lifting a patient onto a stretcher, and can accomplish this with little or no movement of the patient's spine. Safety straps are used to secure the patient to the stretcher.

FIGURE 22.—La Caron Lift Chair, Model 76, helps patient rise from a sitting position.

c. *La Caron Lift Chair Model 76.* This chair (Fig. 22) manufactured and marketed by La Caron Industries, Kenilworth, New Jersey is currently being evaluated. It uses a counterbalance principle to help an occupant to achieve an upright posture. This straight-back recreational chair is intended for ambulatory patients who have difficulty in rising from a sitting position: e.g., patients with arthritis, Parkinson's disease, muscular degeneration, paralysis, multiple sclerosis, cardiovascular accident, and geriatric problems.

6. *Orthotics*

a. *Sani-Comfo Arm Splint.* Manufactured and marketed by L'Nard Associates, Inc., Providence, Rhode Island, this splint (Fig. 23) is designed to be both an alternative to the conventional I.V. board, and a passive positioning hand splint for the wrist and fingers. Constructed of preshaped plaster, the device is available in small, medium, and large sizes in an effort to accommodate its intended users. It employs adjustable Velcro attachment straps and a removable thumb post that makes the device adaptable for either hand. Several units are currently being evaluated at the VA Hospital, Castle Point, New York.

b. *Liberson Electrical Stimulation System.* The Liberson stimulator (Fig. 24) is designed to provide dorsiflexion of the ankle without excessive concomitant eversion or inversion. In addition to stimulating the peroneal nerve (or one of its branches), the tibialis anterior muscle is also stimulated. (Stimulation of the tibialis anterior muscle counteracts the eversion that is usually produced by peroneal nerve stimulation alone.)

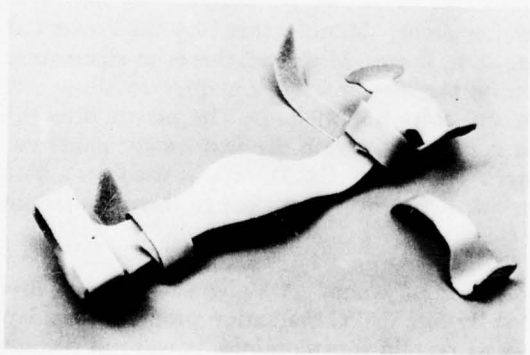

FIGURE 23.—Sani-Comfo Arm Splint.

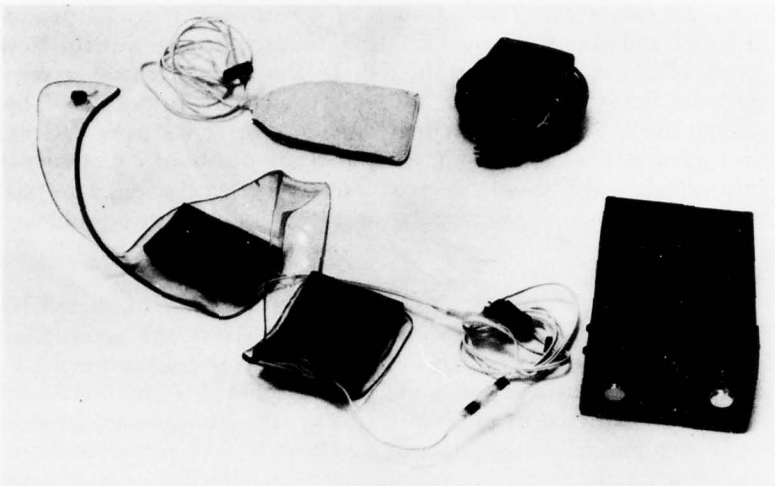

FIGURE 24.—Liberson Electrical Stimulation System is being used to stimulate the paralyzed muscles of hemiplegic patients to provide a more efficient walking pattern.

The Liberson electrical stimulator is being used to stimulate the paralyzed muscles of hemiplegic patients to provide a more efficient walking pattern, and to decrease spasticity of certain muscles in the lower limb of the affected side. Six patients have thus far been fitted with the device and are currently being monitored. Additional hemiplegics will be fitted.

7. *Driving Systems*

a. *Power Car Door.* Manufactured by the Power Car Door Corporation, St. Clair Shores, Michigan, this is an electromechanical device that can be installed inside a car door to allow a disabled person to open and close his car door. The person does this by activating either a control switch on the instrument panel or an exterior control switch. The Power Car Door was used on a Volvo during a 6-month period. It has been returned to the manufacturer with our comments.

b. *Volvo Driving System.* A Volvo servocontrol driving system was evaluated by our VAPC evaluation program for adapted driving systems. Due to certain shortcomings, it was not recommended for general use.

II. COMPLIANCE TESTING

A. Standards

A first draft of *Standards and Specifications for Lower-Limb Prosthetic Assemblies and Components* has been prepared. The scope of these standards includes all lower-limb prosthetic assemblies and components in adult sizes. Copies have been distributed internationally for peer review in preparation for the ISPO-ASTM workshop in Philadelphia, Pa. scheduled for June 1-7, 1977.

B. Testing

1. *Upper-Limb Components*

a. *Internal Elbow Assembly.* Hosmer-Dorrance, Inc., Campbell, California, submitted an Internal Elbow Assembly for annual compliance testing. This assembly complied with the "Tentative Specifications for Adult Size Elbow, Artificial, Internal, Alternating, for Above-Elbow Amputees."

b. *APRL Voluntary Closing Hook.* Hosmer-Dorrance, Inc., submitted an APRL Voluntary Closing Hook for annual compliance testing. This assembly complied with the "Tentative Standards for Hook, Mechanical, Voluntary Closing, for Upper-Limb Amputees."

2. *Lower-Limb Components*

a. *Positive-Locking Knee/Shank Assemblies.* The United States Manufacturing Co., Glendale, California, submitted several Positive Locking Knee/Shank Assemblies, model number 2L104, for evaluation. One sample was tested on the APRL Cycling Machine (Fig. 25) to determine the wear characteristics of the locking mechanism. The shank was flexed 30 deg, then returned to full extension, where automatic locking occurred. The cycling mechanism then unlocked the knee prior to the next cycle. Cyclic speed was 0.4 Hz. The locking mechanism functioned properly for 100,000 cycles, a satisfactory performance.

b. *SACH Feet.* Four manufacturers submitted samples for annual compliance testing. These tests were conducted in accordance with "Standards and Specifications for Prosthetic Foot-Ankle Assemblies, VAPC-L-7007-2, June 1, 1973." All samples submitted by the following companies conformed to the requirements: Wagner Orthopedic Supply Co., Kingsley Manufacturing Co., Otto Bock Orthopedic Industry, and U.S. Manufacturing Co.

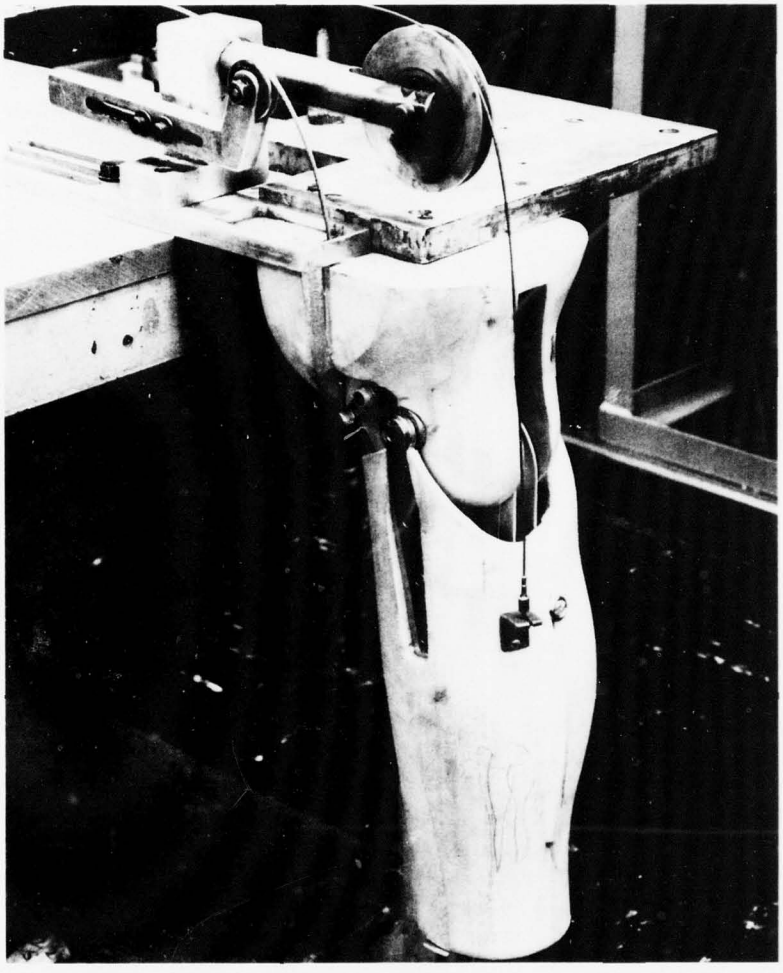

FIGURE 25.—Testing a sample of a U.S. Manufacturing Co. knee on an APRL Cycling Machine.

3. *Adaptive Auotmotive Hand Controls*

The adaptive automotive hand controls of eight manufacturers have been tested and inspected for compliance with "VA Standard Design and Test Criteria for Safety and Quality." Thus far, all of the samples have complied with the standard. (The samples have not as yet been tested for resistance to corrosion.)

The samples submitted by the remainder of the manufacturers are currently being tested and inspected.

III. THE VAPC CLINIC TEAM

The statistical breakdown (Table 1) of the veterans treated by our Clinic Team for the latter half of 1976, shows a typical VAPC case load. It is similar to that shown in previous reports (BPR 10-25 and BPR 10-26).

TABLE 1—*Statistical Breakdown of Patient Disabilities July 1 to December 31, 1976*

Amputation		
Area of involvement	Specific level of involvement	Number of patients
Lower-limb unilateral	Below-Knee	153
	Above-Knee	168
	Transmalleolar (Syme's)	17
	Hip (Disarticulation)	2
	Partial Foot	4
Lower-limb bilateral	Below-Knee	25
	Below-Knee/Partial Foot	1
	Above-Knee/Below-Knee	13
	Above-Knee	9
	Transmalleolar (Syme's)	1
Upper-limb unilateral	Below-Elbow	1
	Above-Elbow	3
	Partial Hand	2
	Shoulder (Disarticulation)	1
Upper-limb bilateral	Above-Elbow	1
	Below-Elbow	2
	Partial Hand	1
Lower-limb and upper-limb	Above-Knee/Below-Elbow	1
Triple	Above-Knee/Below-Knee/Below-Elbow	3
	Above-Knee/Below-Elbow/Above-Elbow	1
	Above-Knee/Bilateral Above-Elbow	1
		(410 Total)

TABLE 1—*Statistical Breakdown of Patient Disabilities July 1 to December 31, 1976 (Cont'd).*

Neuromuscular or Skeletal Impairment

Area of involvement	Specific level of involvement	Number of patients
Lower-limb unilateral	Ankle-Foot	157
	Knee-Ankle-Foot	2
Lower-limb bilateral	Ankle-Foot	17
	Knee-Ankle-Foot	5
	Knee-Ankle-Foot; Ankle-Foot	1
Upper-limb unilateral	Arm-Elbow-Forearm; Wrist-Hand	8
Trunk	Lumbosacral spine	10
Miscellaneous	Varied (Wheelchairs, shoes, etc.)	34
		(234 Total)

Amputation and
Neuromuscular or Skeletal Impairment

Area of involvement	Specific level of involvement	Number of patients
Lower-limb bilateral	Above-Knee/Knee-Ankle-Foot	1
	Below-Knee/Ankle-Foot	1
	Above-Knee/Ankle-Foot	3
Lower-limb and upper-limb bilateral	Transmalleolar (Syme's)/Arm	1
	Above-Knee/Ankle-Foot; Paraplegia	2
	Above-Knee/Arm	1
		(9 Total)

HIGHLIGHTS OF OTHER VA RESEARCH PROGRAMS

PROSTHETICS

Edited By

Eugene F. Murphy, Ph. D., Director

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Research and Development in the Field of Artificial Limbs

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Hans A. Mauch

Hydraulic Ankle Control System

Development has reached the stage where shakedown tests will be conducted by the Research Center for Prosthetics, New York. During this reporting period the following has been accomplished.

1. The difficulties encountered with noises originating from the attachment areas for the hydraulic unit inside the aluminum keel, from the spherical bearing collar around the piston and rod neck, and from the elements for the attachment of the piston rod tip to the inside of the extruded shank tubing have been resolved. It was necessary to find a different solution for each of the three locations. There is still a possibility that some noises will occur in the future as a result of the effects of long-time wear.

2. The loosening of the keel screws has been overcome by making them of one piece of hardened steel, thicker, and with a shallower pitch (1/4–28). In addition, their shoulder angle (and the countersink angle in the keel screw holes) was changed from 120 deg to 82 deg. Finally, non-locking Heli-Coils are used, all this for maximum rigidity.

3. An alternative polyurethane foam compound for the rubber foot has been located. A foot molded of this compound with the same total weight showed better skin formation resulting in a

tougher outside and a softer inside. No wear symptoms were found after 4 months of use.

Foot molds for sizes 9 through 11, left and right, are 100 percent completed, and for size 8, left and right, 50 percent completed.

4. A pre-production hydraulic unit (No. 4) has been made using improved measuring and machining methods and replacing the semi-cylindrical bypass valve inside with a flat one, thus greatly simplifying the manufacturing process for the eight remaining shakedown tests and all future systems. The unit has been test-worn for 2 months without any adverse findings.

Hydraulic Knee Control System for Geriatric Amputees

Development has been continued and has resulted in a prototype design which incorporates the following features:

1. The outside geometry of the hydraulic system will be compatible with all existing above-knee legs which accept the standard length S-N-S system and the standard length swing control systems of other manufacturers. Its cylinder part will be sufficiently shortened to permit the use, at its lower end, of a crossbolt instead of the two cylinder studs presently needed. There will also be sufficient space between this crossbolt and the underside of the cylinder bottom for the optional installation of the eccentric inserts which were formerly used around the two ends of the top bolt of the S-N-S system. Rotation of the crossbolt will then again permit the adjustment of the knee angle at full extension.

2. The stance control elements will remain essentially the same as in the S-N-S system except for a shortening of the piston rod to make possible the geometry described in point 1. The switch lever at the top of the piston rod will be somewhat shortened, to interfere less with full length cosmetic covers of pylon-type legs.

3. The swing control portion will be completely redesigned retaining as much as possible the swing characteristics of the S-N-S system. The displacement of the hydraulic fluid necessary for producing flexion resistance will be provided by the volume of the piston rod itself during its downward motion into the cylinder. The amount of fluid displacement obtained in this manner is slightly more than that produced in the S-N-S system for the same purpose by a special small piston.

The fluid displacement necessary for the extension resistance, including terminal deceleration, is obtained by letting a shoulder

at the lower end of the piston rod enter a closed cylindrical space during its upward motion.

The characteristic profiles of the flexion and extension resistance, respectively, are achieved by specially shaped recessed areas on the surface of the piston rod, which in conjunction with recessed areas in the surrounding elements, provide escape ports for the hydraulic fluid which vary during the piston rod motion in an appropriate manner.

The necessary adjustments of the swing resistances for the individual user are produced by turning these surrounding elements relative to the piston rod. Since these elements are attached to the cylinder wall, turning of the cylinder within the cylinder bottom will adjust both the flexion and extension resistance simultaneously in a balanced manner, thus eliminating the need for separate adjustments which led to confusion in many cases.

4. Great care has been devoted in the design to the "air management" problem, which means the design features which will reduce the likelihood of air getting into the wrong places inside the hydraulic system during unusual (horizontal or upside down) working positions, and which will speedily eliminate air which does get into the wrong places, as soon as normal walking motions are resumed.

5. A special effort has been made to avoid as much as possible mechanical friction throughout the hydraulic system and to reduce its weight and cost, all especially important for a geriatric amputee.

Testing of various basic design elements, particularly for the radically new swing control, has started. No insurmountable difficulties have been encountered so far and there seems to be a good chance that the resulting hydraulic system will not be restricted to the use in geriatrics, but may develop into a successor to the present S-N-S system, with a lower price and longer life expectancy.

No reportable progress was made in the development of the *Voluntarily Actuated Swing and Stance Control System* because of higher-priority work.

New Three-Part Knee Bolt Design

The development of the Three-Part Knee Bolt is completed. In October, drawings (Fig. 1-5), sample bolt assemblies including side straps, and a typical bid for the manufacturing of these bolts in quantity have been made available through the VA to interested suppliers. The new bolt design has the following advantages:

1. Closer control of side-play on the knee bolt.

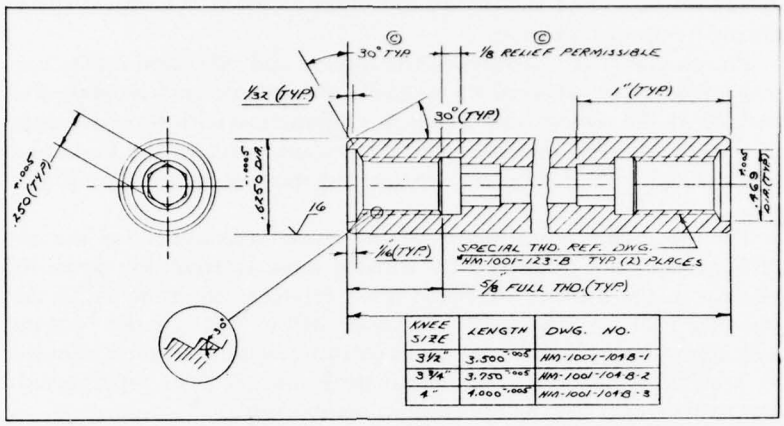

FIGURE 1.—Knee bolt. The shop drawing reproduced here also carried notes as follows: 1. Both threads and o.d. must be concentric within .005 T.I.R., and coaxial with each other and square with bolt ends within .002 in. per in. 2. Remove all burrs. The material was noted to be 5/8 o.d. 3/16-wall seamless steel tube.

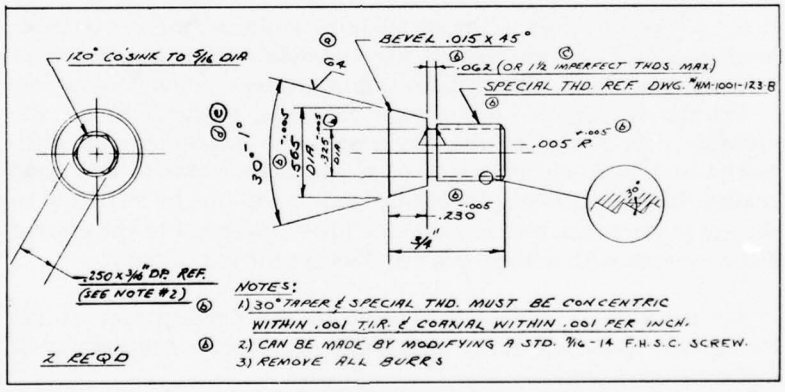

FIGURE 2.—Knee bolt screw.

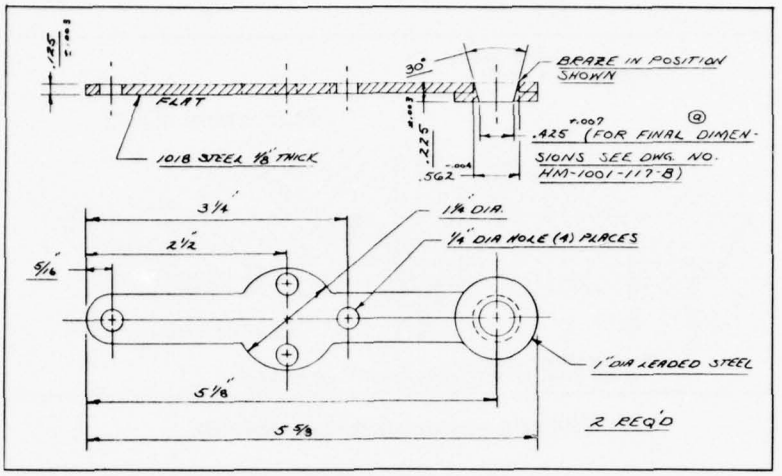

FIGURE 3.–Shin strap, first operation in fabrication.

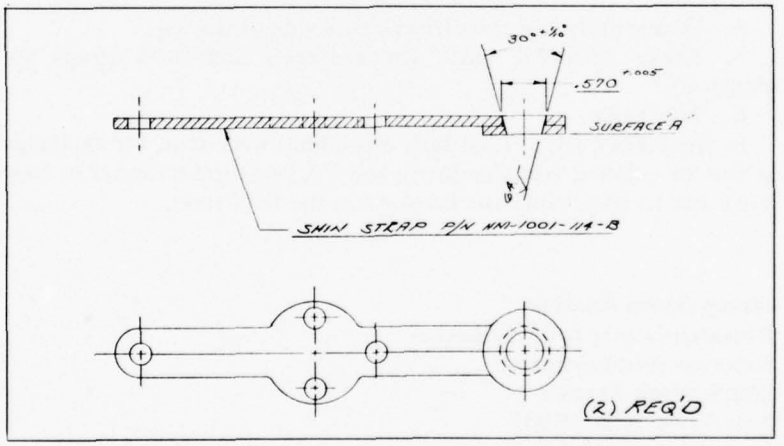

FIGURE 4.–Shin strap, second operation in fabrication. The shop drawing reproduced here also carried the note: "Centerline of tapered hole must be square with surface 'A' within .001 in. per inch."

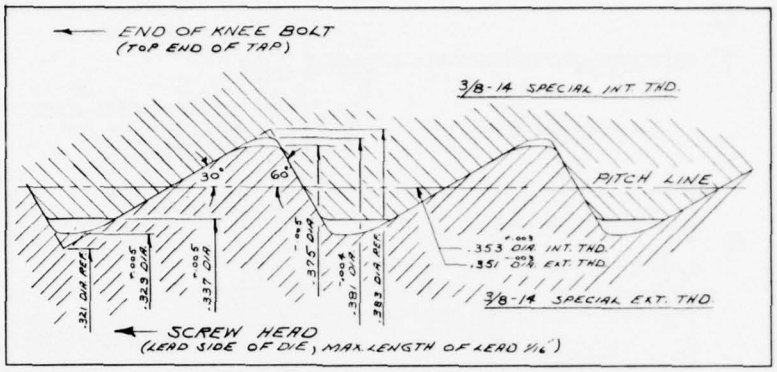

FIGURE 5.—Thread data, three-part knee bolt.

2. All parts are positively interlocked (no slippage or noise at load reversal).
3. No left-hand thread needed to prevent bolt rotation in either direction.
4. Disassembly can start from either side of the leg.
5. Fewer different parts (both screws and both straps are identical).
6. Low price.

In November 1976, final bolt assemblies were sent, for exchange in the 24 existing test shanks, to the VA Prosthetics Center in New York and to all prosthetists involved in the field tests.

Stump Stress Analysis
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Within this report period, Mr. Bennett left his position with NYU to accept a position at the Research Center for Prosthetics of the VA. While the effort concerning stump stress will continue at the VA, there has been a hiatus during which a suitable laboratory facility will be prepared. It is anticipated that research efforts will resume in the summer of 1977.

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Synergetic Hook and Hand

Twelve prototypes of the synergetic hook, a powered terminal device developed in this laboratory, have been produced by a manufacturer under a Veterans Administration Prosthetics Center (VAPC) contract. These prototypes are to be evaluated in a small clinical study coordinated by the Research Center for Prosthetics and directed by the VAPC. The hook, which is interchangeable with a hand, is shown in Figure 6. The amputee pictured in Figure 6 is preparing to attach the hook to the prosthesis.

Specifications for the synergetic hook are as follows:

1. Closing/opening rate, typically $\geqslant 4$ rad/s;
2. Closing time from full-open position $\cong$ 350 ms;
3. Maximum opening $\cong$ 80 deg (4.25 in. between fingertips); and,

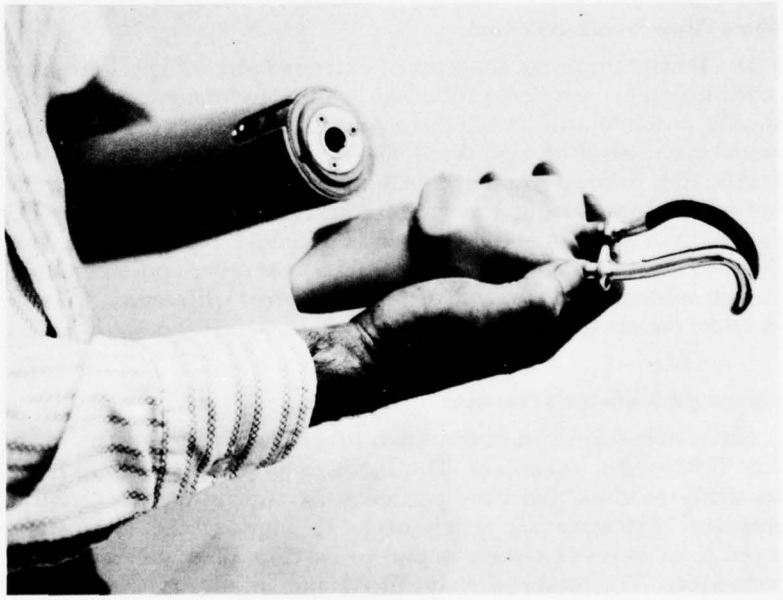

FIGURE 6.–Synergetic hook, which is interchangeable with a hand. Amputee is shown preparing to attach the hook to the prosthesis.

4. Maximum pinch force ≅ 25 lbf (111 N).

Patients fitted with this device have responded favorably to its performance.

Preliminary success with the synergetic hook has resulted in the development of a synergetic hand in this laboratory. This hand is based on the same design principles as the synergetic hook. Problems associated with a cover and glove for this hand are being examined. The soft inner liner and glove must be very flexible in order not to inhibit the "fast" fingers of the synergetic hand.

The synergetic hand is desirable to complement the synergetic hook because interchangeable hands and hooks should have dynamic responses which are similar. One hand has been fabricated in the laboratory and attempts to develop suitable cosmetic covers are underway.

Further development of the synergetic hook/hand and associated controls is continuing. It is desirable to reduce battery size in order to minimize weight, and to make possible a control unit which is compatible for wrist-disarticulation amputees as well as other below-elbow amputees.

Above-Elbow Prosthesis Control

Dr. David Simpson's concepts of extended physiological proprioception (e.p.p.) are being followed in the development of an electrically powered arm having three degrees of freedom. A laboratory model for control of a powered elbow has been constructed. A hydraulic link is being examined to form the connection between input and output. In this way the output can be reflected at the input without the orientation demands necessary for cable linkages. The object of the work is to construct a controller and arm which permit subconscious control of several degrees of freedom for the shoulder-disarticulation amputee.

Lightweight Below-Knee Prosthesis

Seven below-knee amputees (two bilateral) have been fitted with nine lightweight prostheses. The lightweight prostheses have been favorably received and have particular advantages for the geriatric amputee. Attempts are being made to improve the fabrication process, to improve cosmesis, and to develop alternate suspension techniques. Prostheses already fitted and in use are now being modified or replaced—this is instead of fitting more recently developed versions to new subjects.

Thoracic Suspension Harness

The thoracic suspension harness continues to be evaluated on above-elbow amputees. This technique has also been applied successfully on subjects with orthotic problems.

Atmospheric Pressure Suspension Systems

Two self-suspending prostheses for above-elbow amputations are being fabricated. Atmospheric pressure suspension (APS) of prostheses was examined extensively in this laboratory a few years ago. The technique was successful but there were problems with socket materials and the fabrication technique was not simple enough for wide use. Also, a cast modification approach which was applicable to a wide range of amputees was not thoroughly developed.

One socket will be used with myoelectrically controlled hand prostheses and Otto Bock arm pylon. The other socket is for a congenital amputee who wishes a prosthesis for playing racquet ball.

Northwestern University Below-Elbow Socket

A casting technique using alginate is being developed for below-elbow sockets. The socket design as originally proposed by John N. Billock calls for an undistorted impression of the limb to be taken. A casting fixture which automatically sets proper elbow flexion and which contains the alginate has been constructed. The method is simple and not expensive. When coupled with Billock's cast modification scheme, and cellulose acetate butyrate (CAB) for a check socket, it is possible to obtain excellent prosthetic fittings.

Fundamental and Applied Research Related to the Design and Development of Upper-Limb Externally Powered Prostheses

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Control of an Artificial Limb with Several Degrees of Freedom of Motion

Work at the Biotechnology Laboratory during the period of June 1976 through December 1976 concentrated on the following subjects:

1. Development and assembly of a microprocessor control system for a prosthesis with three degrees of freedom of motion;

2. Development, finalization, and testing of pattern recognition for a given amputee subject;
3. Continuation of the investigation of proper codes, pulse widths, and phase shift parameters to optimize electrotactile information transmission for sensory feedback purposes from a prosthesis with three degrees of freedom of motion.

An RCA-COSMAC microcomputer development system was purchased to develop the control system hardware and software for the prosthesis. This system includes the microprocessor kit, COSMAC microkit interface with an 1802 emulator, and COSMAC floppy disk system. The various components were set up, interfaced, and debugged. In addition, the microprocessor was assembled in a belt-mounted package 6 in × 4 in × 1½ in. The continuation of the work awaits shipment of the memory chips from RCA.

The amputee experiments included the demonstration of myoelectric control in conjunction with pattern recognition techniques. The experimental setup is composed of the following components (shown in the block diagram of Figure 7):

1. The computer (an Interdata Model 70) with its associated peripheral support equipment;

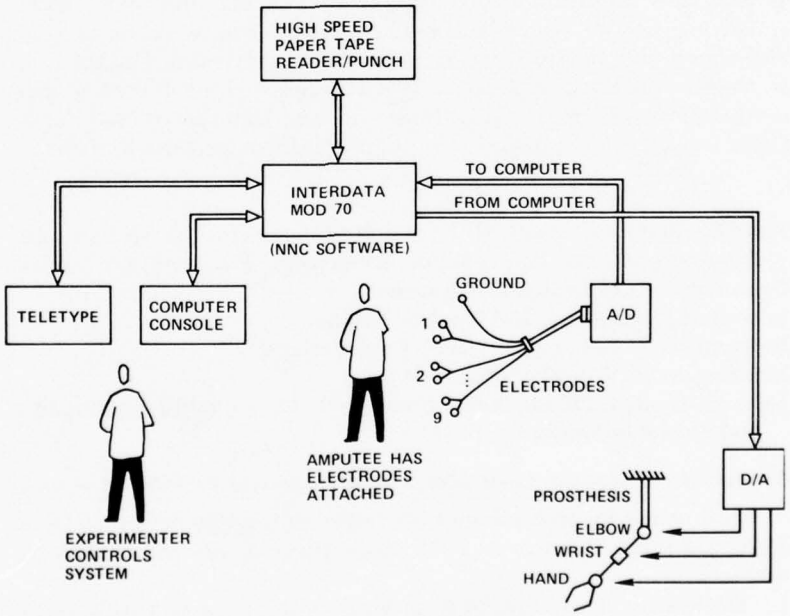

FIGURE 7.—Hardware components for experiment.

2. The A/D converter and nine pairs of myoelectric signal (MES) amplifiers, and

3. A prosthesis with three degrees of freedom of motion.

The amputee sat in a chair with nine electrodes (plus a ground) attached to the body (Fig. 8). The experimenter, in conjunction with the subject, trained the computer to recognize myoelectric signals (MES) from the electrodes. The computer then used a pattern recognition technique called the Nearest Neighbor Classifier (NNC) to determine, from the incoming MES, which motors of the prosthesis to actuate (i.e., how to move the prosthesis).

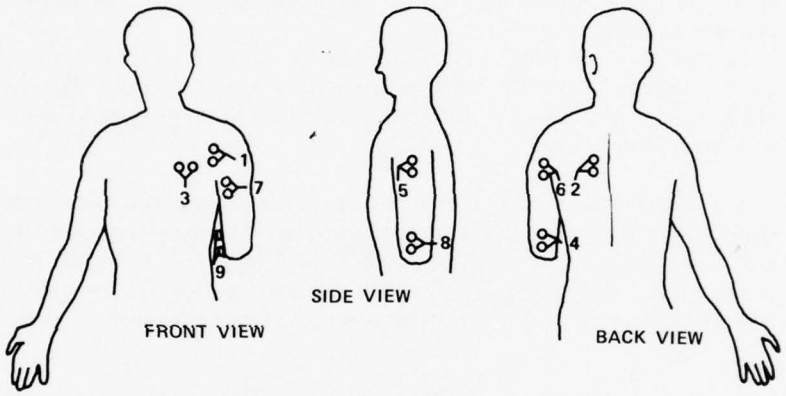

FIGURE 8.–Typical placement of electrodes on a subject's body.

The prosthesis was attached to a test stand located near the subject and properly oriented in relation to the amputated arm. Three degrees of freedom–elbow, wrist, and hand (opening and closing)–were available for computer control.

Results

The first experiments were used to determine the relation of MES inputs to system performance. A single group of nine MES inputs (one for each electrode) can be used by NNC or many such groups can be read in, averaged, and used. Experiments determined that averaging together 128-144 such groups (each group composed of nine electrode signals) resulted in better prosthesis control. This may be because of the sample size or because of the delay caused by more input: this remains to be determined.

Later experiments concentrated on training several degrees of freedom at once. Results of these experiments showed that the subject could control elbow, wrist, and hand movements independently. Some coordinated movements were also trained with reasonable results. These were: a combination of elbow flexion and wrist pronation, and a combination of elbow extension and wrist supination. (Although the combinations of elbow flexion-and-supination, and elbow extension-and-pronation, are considered more functional patterns of motion, the subject was easily trained to control these motions.) Control over nine functions was obtained in some experiments (elbow flexion, elbow extension, wrist pronation, wrist supination, hand-open, hand close, combined elbow flexion and wrist pronation, combined elbow extension and wrist supination, and rest (no movement)).

Electrode placement was found to be important in obtaining good control. Better electrode placement resulted in more distinct MES inputs and allowed the computer to make a movement decision more accurately.

The investigation of the response of tactile sensation to electrical stimulation via two adjacent electrodes, in order to determine the two-point-discrimination threshold as a function of frequency, pulse width, and phase shift within the two pulses, is being continued. Current data are too preliminary for reliable results.

Design of Prosthetic and Orthotic Devices and Biomechanical Studies of Locomotion

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Charles W. Radcliffe, Don M. Cunningham, and James M. Morris, M.D.

Design of Lower-Limb Prosthetic and Orthotic Devices

1. *Four-Bar-Linkage Polycentric Pneumatic Knee*

Further development of cosmetic covers for the four-bar knee was undertaken in response to feedback from a commercial vendor who quoted very high prices for the two main parts of the original knee fairing. A new one-piece preshaped fairing of semiflexible foam has been designed to reduce costs and provide a resilient knee with improved cosmesis and simplified assembly. Construction of a

mold for the knee fairing has begun. The new design also allows significant simplifications in the spherical alignment coupling and socket attachment.

2. *Six-Bar-Linkage Unit with Friction Swing-Control*

Twelve units were produced by the Navy Prosthetics Research Laboratory (NPRL) in Oakland, California. Tests on four subjects have revealed generally good function but inadequate strength in the proximal bearings. A design revision to achieve greater bearing resistance to lateral bending moments was undertaken.

3. *Friction-Stabilized Knee*

The knee-brake of the friction-stabilized knee is designed to engage at heel contact but automatically release when weight is transferred to the forefoot. This automatic control is achieved by appropriate alignment of a swinging link that carries the brake and knee bolt. The first prototype, reported earlier, was unsatisfactory because the brake re-engaged as soon as the knee was bent just prior to toe-off, preventing the desired smooth entry into swing phase. A second prototype, completed during the present report period, effectively corrected these stance-phase problems by relocating the swinging link in the shank, distal to the knee bolt.

Another design goal was to obtain a useful swing-control function by means of the same brake that provides knee stability at heel contact. However, the new unit could not be adjusted to provide a smooth and reliable swing-control torque because of a foot-heavy distribution of mass in the shank. Development will continue.

4. *Tube Couplings for Modular Protheses*

Eight units of the simplified version of the internal expanding coupling for VA standard 35mm pylon tubing have undergone amputee or machine tests. These include two couplings built into the metal keel SACH feet, three couplings for conventional SACH feet, and three distal knee couplings. No problems with strength have appeared, but occasional difficulties in releasing the couplings after test were encountered. A search for a more suitable material for the expansion collar will be undertaken.

5. *SACH Foot with Metal Keel*

Two additional models of the previously reported aluminum keel SACH foot, with integral pylon coupling and solid rubber cushion at the forefoot, were molded with the aid of NPRL. One was tested by Hosmer-Dorrance Corp. for 80,000 cycles of simulated walking and the other was worn by an above-knee amputee

for approximately 3 months. At the end of these tests, both feet had worn through the molded foam under the forefoot to expose the solid rubber cushion. The tip of the rubber cushion had fractured in the machine-tested model. The aluminum keels and pylon couplings showed no structural problems, but the coupling on the machine-tested unit was difficult to remove after the test. Refinement of this design will continue.

Biomechanical Studies of Human Locomotion

1. *Gait Dynamics*

Analysis of joint work and segment energy was interrupted by the departure of Dr. M. Y. Zarrugh from the laboratory to assume an academic position elsewhere.

As a continuation of previously reported studies of gait dynamics, kinematic data from six additional normal male subjects were obtained on the treadmill at each of six different speeds. Simultaneous recordings were obtained, by use of string transducers and electrogoniometers, of pelvis motions (three linear and three angular) and flexion angles of the right hip, knee, and ankle.

Considerable variation among subjects was observed. Comparisons with previous data and with data from other laboratories revealed some unusual characteristics in the vertical motion curves. It is suspected that these may be artifacts resulting from the nature of the body attachments used. Based on experience with the clinical goniometers, revisions of the laboratory instrumentation were undertaken to include both right and left legs and to provide a more precise reference of body segment positions to the vertical.

2. *Unequal Leg Length and Low Back Pain*

Unilateral low-back-pain in patients with unequal leg lengths has been the subject of a collaborative project with a local physician. The first order of business has been to develop reliable objective methods for assessing inequality of leg length. X-ray exposures have been made to check the accuracy of a non-invasive technique that uses a leveling frame in contact with right and left iliac crests. In practice, lifts are placed under the short leg until the level indicates that pelvic list has been eliminated.

Considerable difficulty was encountered in trying to obtain reliable leg length measurements—even from the X-ray exposures. To obtain good correlation between the size of the lift placed under the foot and the amount of lift at the femoral head indicated by the X-ray exposure, it was necessary to take four precautions: (i) include an independent horizontal reference in each exposure,

(ii) control the spacing between the feet, (iii) position the X-ray source at the level of the higher femoral head, and (iv) insure that both knees are extended at the instant of exposure. On patients without marked asymmetry of the pelvis, the non-invasive technique appears to be quite accurate.

Following development of reliable methods for static assessment of leg length inequality, an attempt will be made to identify dynamic gait measurements that can be used to assess functional leg length inequality and to help with assessments of the therapeutic value of corrective lifts.

3. *Instrumentation for Clinical Gait Evaluation*

As previously reported, a portable measurement system for clinical gait evaluation was developed as a simplified outgrowth of special instruments that had been designed for kinematic measurements in the locomotion laboratory. The system includes four basic elements: (i) an instrumented walkway for measurement of average velocity, step duration, and step length in completely unencumbered patients; (ii) a lightweight set of precalibrated self-aligning goniometers for simultaneous measurement of flexion angles at both hips and both knees; (iii) foot switches for use with the electrogoniometers to detect hindfoot and forefoot contact of both feet; and, (iv) an oscilloscope display that simultaneously presents hip-knee angle diagrams for both left and right legs.

The angle diagrams are X-Y plots of hip flexion versus knee flexion. They are desirable because they clearly show interaction between hip and knee during walking, and they allow superposition of successive walking cycles without the need for oscilloscope synchronization. Changes in hip-knee coordination cause evident changes in the shapes of the patterns, as do changes in walking speed. Photographs of the diagrams, along with records of velocity, step length, and step duration, are filed in the patient's medical records.

During June of 1976, a test of this system was undertaken in collaboration with the Walking School of the Department of Orthopaedic Surgery, University of Uppsala, in Sweden. During the summer the system was installed and tested and an experimental protocol was established. Tests of patients are to continue for approximately one year with particular attention to amputees and candidates for total joint replacement. As of January 1, 1977, 22 patients had been examined, including 6 above-knee and 3 below-knee amputees, and 8 preoperative and 5 postoperative joint-replacement patients.

Experience with the system to date provides a basis for some preliminary observations and conclusions—

The hip-knee angle diagrams are an effective display for illustration of hip-knee coordination and the effects of reduced hip and knee joint mobility.

With the exception of the foot switches, which were troublesome, the system was easy to apply, reliable, and effective at documenting several significant gait variables.

Automatic processing and display of foot switch data (which is not possible with the present system) would be an essential feature for a truly practical clinical instrument.

On the 10-meter walkway, a single electrical cable connected to the patient presented little or no difficulty during the testing.

The ability to measure velocity, step length, and step duration both before and during instrumented runs is a valuable safeguard against alteration of the patients' gait by the goniometers.

Precalibration of sensitivity and zero settings of the goniometers is absolutely essential for a simple and quick experimental procedure.

Mobility Aids for the Physically Handicapped

1. *PRAHN Wheelchair*

The Berkeley tests of the preproduction PRAHN (Powered, Reclining, Adjustable-Height, and Narrowing) wheelchairs suggested a number of design changes, primarily larger batteries and motors, increased ground clearance, and smaller rear wheels to better clear the armrest. The redesign incorporating these changes is well under way, with working drawings expected in October 1977. The new chair will incorporate a linkage for properly constrained recline kinematics, as well as a spring suspension and curb-climber option.

A. *Fail-Safe Brake.*—A solenoid actuated brake, that is activated when the power to the solenoid is interrupted, has been designed and is currently being tested on the spring suspension powering unit. The brake will also be used on the new PRAHN wheelchair.

B. *Spring Suspension Powering Unit.*—The spring suspension powering unit has continued to perform well. Further developments have been made and there are plans to make ten of these locally.

2. *Urinal Bag Clamp*

A urinal bag tube clamp has been designed that allows a quadriplegic to empty his urinal bag with a light pull of a string. Initial tests have been very successful.

Immediate Postoperative Prostheses Research Study
Prosthetics Research Study
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VAH Seattle Amputee Service

The Prosthetics Research Study staff has maintained an active relationship with the clinical services at the VAH, Seattle, Wash., and at its Prosthetic Treatment Center. The inpatient amputee service is under the direction and supervision of the PRS staff. This staff includes three attending surgeons and a research physical therapist who is based at the VAH, Seattle, Department of Physical Medicine and Rehabilitation. Research prosthetic service and technician assistance are also provided to the Veterans Administration Hospital, as required, for proper conduct of the Amputee-Prosthetic Service. A program of rounds each week with both the General and Orthopedic Surgical Services, and occasionally the Rehabilitation Medicine Service, is conducted. Our staff also participates in the twice monthly amputee discussion sessions, which provide an on-going educational service for inpatient and outpatient amputees.

During the time interval covered by this report, 39 amputation procedures were performed by or under the direct supervision of PRS surgeons; 145 rigid dressing changes were carried out; and 8 patients were treated by the Controlled Environment Treatment system. The readily available inpatient consultation service provides a valuable liaison between the study group and the clinical personnel at VAH.

Prosthetic clinics are held 3 times per month at the Prosthetic Treatment Center, VAH. During the 6-month period, 185 outpatients were assessed for various prosthetic problems. Time is allotted at these clinics and on inpatient rounds to give all physical therapy students affiliated at VAH an opportunity to work with and to learn about amputees. Time is also spent with residents on the Rehabilitation Medicine Service. Visitors are welcome and are in frequent attendance at the clinics and at the inservice rounds.

The PRS-Moore Load Cell continues to be evaluated by our physical therapy staff at the hospital.

Some experimental work has been performed in *residual limb muscle training,* using either biofeedback or a modified pressure cuff. Records on research patients are kept both at VAH and at PRS.

Amputee Discussion Groups

A patient discussion group was initiated in June 1976. The main goal was to bring patients together in a semi-social setting to exchange information concerning prostheses, surgery, and amputee life, as well as how to cope with the general hospital system. Additional goals were to help alleviate patients' feelings of helplessness, isolation, and depression, and to facilitate staff awareness of psychosocial factors which influence patient rehabilitation.

The group, arranged and coordinated by the physical therapist, meets for 1 hour twice a month. All inpatients, and those outpatients who can, are encouraged to attend, verbalizing their opinions and suggesting topics of discussion. Different speakers are arranged for each session, and these have included physicians, nurses, physical therapists, occupational therapists, prosthetists, social workers, recreational therapists, and other amputees. Topics have included peripheral vascular disease, diabetes mellitus, prosthetic fabrication, care and cost of prostheses, diabetic foot care, residual limb management and pain, driver training, psychosocial adjustment, sex, sports and recreation. Several movies designed for patient viewing have been used. Approximately 10 to 15 patients attend, and because of their positive reactions, we plan to continue the meetings.

Functional Capabilities Survey

The aims of the functional capabilities survey were to obtain information directly from the patients on activities generally considered essential for daily living, vocational and extra-ambulatory activities, living arrangements and adjustments in them, as well as feedback on what professionals in the rehabilitation field should be doing to maximize the amputee's lifestyle. We also attempted to ascertain what relationship level of amputation, age, and cause of amputation had to patient rehabilitation achieved.

Controlled Environment Treatment

Our preliminary evaluation of 20 below-knee amputations managed postoperatively with Controlled Environment Treatment (CET) has been submitted for publication. To date, we have utilized CET in 32 cases and presently continue to study this system of management as an alternative to the Immediate Postoperative Prosthesis Management (IPPM) and as a means of edema control.

Patients managed with either postoperative method undergo $Xenon^{133}$ testing to assess skin blood flow in the ischemic limb. Those cases utilizing CET provide additional information by means

of a small strain gage sutured adjacent to the operative site, which continuously reflects and records fluctuations in residual limb volume. These data, in addition to clinical observations of wound healing progress, levels of pain, and rehabilitation, constitute the second phase of this study.

We have recently allocated a CET unit to Harborview Medical Center, affiliate of the University of Washington School of Medicine, Seattle, to evaluate its use in treatment of severely traumatized limbs. A smaller version of the CET, the MACE, has been developed by PRS and loaned to Dr. Frederick A. Matsen, III, at the University of Washington for basic animal research of pressure/circulation relationships in skin and muscle. Results of these studies will enable us to establish optimum CET pressure/time cycle parameters in clinical application.

In October 1976, PRS met with representatives of the British CAPE Engineering Company to discuss our clinical experience with CET as a partial basis for its use once it becomes commercially available.

Modulated Air Controlled Environment (MACE)

We have designed a unit, MACE (Modulated Air Controlled Environment), in an effort to reduce the size, weight, and cost of the CET system without compromising its efficiency. This unit is one-sixth the size of the CET. It does not have nor need the sterile environmental capabilities of the CET. The MACE unit was evaluated by the local N.F.L. football team of which seven players with various knee and ankle sprains were treated. Only one player reported negligible results in reduction of edema, while the remainder had an estimated 25 to 75 percent reduction in edema. Further evaluation and modifications of the equipment will be conducted in the coming year.

Rancho Edema Control System

Rancho Los Amigos Hospital, Downey, California, has been working on a project similar to the MACE; i.e., the Rancho Edema Control System. We are presently evaluating four units and have submitted preliminary reports to VAPC, New York, and to Rancho Los Amigos Hospital.

Xenon^{133} Testing

Lower limb skin blood flow research, as it relates to amputation level determination, continues at PRS with the assistance of the University of Washington, Department of Bioengineering. To date, radioactive Xenon^{133} has been administered intracutaneously to

19 below-knee amputees. Comparison and evaluation of pre- and post-operative flows in the first 20 cases are to be reported in a forthcoming publication jointly prepared by PRS and the University.

Strain Gages Monitor Surface Skin Tension

The strain gage application was specifically designed to evaluate the efficacy of CET in edema control. A miniature split proving ring with strain gages allows a record to be made of surface skin tension between two sutured points. A pilot study has indicated that there is a distinct increase in residual-limb pressure, occurring a few days postoperatively, and then a decrease over the next 7 days to a nonmeasurable pressure. Continued evaluation is being carried out in conjunction with the CET program.

Electrospinal Instrumentation (ESI)

PRS is one of 18 centers in the United States, Canada, and Sweden involved in the evaluation of Electrospinal Instrumentation (ESI) for the correction of scoliosis. Working with Dr. Walter Bobechko of Toronto, Ontario, Canada, and Medtronic, Inc., Minneapolis, Minnesota, we have implanted units in two patients. While there has been no dramatic correction of the scoliotic curve, neither patient has progressed to the point where further corrective surgery is deemed necessary.

Neuromuscular Assist (NMA)

PRS has not been actively involved in the NMA program since the termination of CPRD. However, recently, one of our six patients required replacement of his implant device; there was no problem encountered in the replacement procedure, and the explanted unit was returned to Medtronic, Inc., for evaluation of the failure. It should be noted that the patient would not consider anything but replacement of his implant unit; he would not consider returning to an external mechanical orthotic device to correct his drop foot.

Functional Electrical Stimulation

Surface stimulation for muscle retraining continues intermittently. Six new patients have been treated. Diagnoses include four hemiplegics, one Erb's Palsy, and one hand problem of unknown etiology. Four of the six patients continue to use the stimulator, with some subjective improvements in function. One patient discontinued stimulation because of increased pain directly related

to stimulation. The sixth patient expired secondary to other medical problems shortly after stimulation was initiated.

Transcutaneous Nerve Stimulation (TNS)

Transcutaneous nerve stimulation has been utilized to relieve a variety of pain problems in 26 cases. Twenty of these patients had phantom or residual limb pain; the remainder were treated primarily for acute joint discomfort. This method appears to be useful in controlling these types of pain.

TNS has recently been widely reported in the literature. Therefore, PRS will continue a long-term followup on the present amputee patients rather than accept additional new patients in the study.

PRS-Moore Load Cell

VA Prosthetics Center, New York, has placed an order for 25 load cells to be evaluated at various centers throughout the United States. Centers are presently being selected, and an evaluation protocol is being outlined. As an ongoing project, we are still considering reduction of size, weight, and cost of the unit, without sacrificing reliability.

Physiological Suspension

Muscle stabilization in amputation surgery, as advocated and utilized by Prosthetics Research Study since its inception, is a viable concept which provides a functional end organ to interface with the prosthesis. Certain below-knee amputees have been observed to have the capability of facilitating suspension of a prosthesis with their residual limb musculature. This capability potentially affects amputation surgery, prosthetic design, and rehabilitation.

Photogrammetry, EMG, and pressure-transducer readings, evaluating the muscle activity occurring during the gait cycle, were completed in six patients. X-rays taken under dynamic conditions demonstrated muscle bulk shift and residual-limb/socket displacement. Assimilation of muscle activity data is continuing at PRS, and a preliminary report on our initial evaluations is nearing completion.

Functional and Stress Analysis of Lower-Limb Amputees Performing Extra-Ambulatory Activities

In cooperation with Drs. Doris Miller and Robert Hutton of the Department of Physical Education, University of Washington, the performance of a number of young lower-limb amputees treated by the PRS staff have been analyzed, using computerized force-

plate studies and multiple exposure photography. These evaluations were carried out with the amputee performing extra-ambulatory functions; i.e., running, jumping, and participating in sports (water and snow skiing, golf, etc.).

The purpose of these studies is to determine the functional capabilities of amputees using standard prostheses, and to study the stress levels and force action parameters to which the prostheses are subjected. Valuable information is forthcoming relative to—

1. The functional capabilities of amputees in high-level performance, particularly involving sports;
2. A critical analysis of the ground-reaction forces involved in the performance of these specific extra-ambulatory functions;
3. The role of training in developing and improving performance; and
4. Prosthetic function, durability, engineering, component, and alignment parameters, relative to extra-ambulatory activities.

The value of this information as it relates to amputation surgery, and to postsurgical treatment including training and prosthetics, is substantial. The amputee population with which we deal has evidenced intense interest in these ongoing clinical studies.

Publications

1. Kegel, B.: Controlled Environment Treatment (CET) for Patients with Below-Knee Amputations. Physical Therapy, 56(12):1366-71, December 1976.

Below-Knee Amputation with Immediate Postoperative Fitting of Prosthesis

VA Hospital
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Wesley S. Moore, M.D., Albert D. Hall, M.D., and Leigh A. Wilson

No progress report was submitted by this contractor for this report period.

Interdisciplinary Development and Evaluation of Externally Powered Upper-Limb Prostheses and Orthoses

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During the latter portion of 1976, research at Johns Hopkins continued to be focused primarily on evaluation and modification of the experimental powered medical manipulator/worktable system. In addition, by prior agreement, a third powered medical manipulator/worktable was completed and delivered to the VAH, West Roxbury, Massachusetts, for further clinical evaluation.

Observation and followup on the clinical performance of externally powered above-elbow and shoulder-disarticulation prostheses fitted in previous years was continued.

Powered Medical Manipulator

The experimental model of the powered medical manipulator previously described in BPR 10-24 and 10-25 has now undergone 2 years of evaluation including over 1 year of clinical evaluation by a high-level quadriplegic. This individual uses this system for a few hours per day to carry out vocational and personal tasks and finds the unit to be of value in his activities of daily living. The arrangement of the equipment relative to the subject in bed is shown in Figure 9. During this reporting period some additional features have been incorporated into the system. They include the following:

1. *New Terminal Devices*

The original manipulator used a Dorrance VO-555 terminal device for grasping purposes. While adequate for many purposes, it did not provide a secure grip for handling magazines and books.

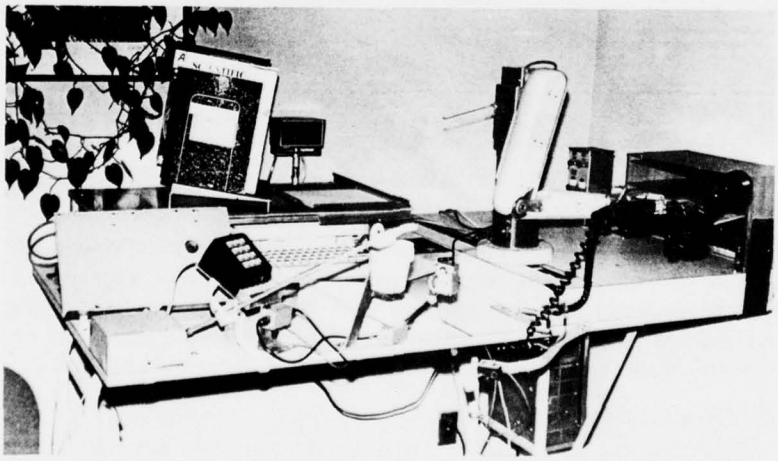

FIGURE 9.–Manipulator/worktable: arrangement of components.

FIGURE 10.—Modified terminal device.

A new terminal device arrangement, shown in Figure 10, was designed to increase the area of the grasping surface. This design proved superior for the purpose and was incorporated into the system for patient testing. The quadriplegic now has used this device for more than three months and finds it very satisfactory.

2. *Eyeglass Control Mode*

The experimental model of the manipulator has been modified to allow eyeglass control of the discrete or pulse commands re-

FIGURE 11.–Eyeglasses used to mode-select manipulator motions. A sensing accelerometer is located on the eyeglass frame.

quired to select each mode of operation. A sensing accelerometer is located on the eyeglass frame (Fig. 11) and pulse commands are generated by "teeth-clicking" modes. The test subject finds this means of control easy to use, with minimal false signal inputs. (The alternate method of pulse input utilizes a microswitch located over a suitable muscle–the test subject prefers the eyeglass mode of control to the microswitch because of occasional muscle spasticity.)

3. *Self-feeding Arrangement*

One of the important features of the powered medical manipulator is its capability for allowing self-feeding by the patient. In order to facilitate this task, three modifications have been made to the system:

a. *Redesigned Eating Utensil.*–A new eating utensil, shown in Figure 12, was designed to simplify the mechanics of self-feeding. It interchanges directly with a removable portion of the special terminal device. The mechanism geometry allows good scooping action at the plate and the spoon remains reasonably horizontal between the plate and mouth.

FIGURE 12.—Special utensil and compartmented plate for use with the manipulator.

b. *Special Compartmented Plate.*—During the early trials of self-feeding, it was apparent that the shape of an ordinary dish and interaction between the spoon and the food made the self-feeding task very tedious. A new plate was designed and constructed with compartmented areas to facilitate scooping of the food. This is also shown in Figure 12. Self-feeding has been demonstrated to be significantly improved by the use of this plate.

c. *Sequence Program Mode.*—In order to minimize input commands in the eating sequence, portions of the trajectory have been automated with hardwired logic. This has significantly reduced the control effort required to eat a meal. The subject reports that self-feeding is now easy and practical with this machine. Future developments described below will further simplify this activity.

Advanced Powered Medical Manipulator with Microprocessor Control

A new manipulator/worktable arrangement is under construction to further simplify the interface between the subject and the machine. This new manipulator will be controlled by a microprocessor in deterministic portions of trajectories but will still permit manual control at the end points and allow override at any time. Such a systems concept allows manual control flexibility when needed, yet utilizes automation for routine aspects of control, thus minimizing sequential inputs from the subject. The automation of the manipulator can be done at low data rates as motions are sequential, an ideal job for a microprocessor.

The design functional requirements for the microprocessor are to—

1. Control the motion of all six degrees of freedom;
2. Monitor the positions of all six degrees of freedom;
3. Be capable of initially executing four programed sequences with expansion capability to 100 sequences;
4. Drive the display readouts; and
5. Do signal processing from discrete and linear input commands from the patient.

General requirements for the selection of the microprocessor hardware for this system included—

1. Low parts count,
2. Complete computer with memory on one board (preferred),
3. Low power requirement,
4. 8-bit arithmetic capability, and
5. Versatile firmware monitor program for debugging.

Interface capability requirements for selection of the microprocessor hardware included—

1. Single channel 8-bit digital-to-analog converter,
2. 8-channel 8-bit analog-to-digital converter,
3. Serial output channel,
4. Two level interrupt, and
5. Teletype.

The Choice—The selection process resulted in the choice of a Mostek F-8 Evaluation Kit with the following characteristics:

1. Four 8-bit I/O ports,
2. Total computer board size with 1K byte memory is 6.75 in × 5.5 in,
3. Total computer power consumption is 5.2 W,
4. 64-byte scratchpad memory,

5. Two real-time clocks,
6. Two external interrupts,
7. 110 and 300 baud (pulses-and-spaces/sec.) interface, and
8. Powerful monitor for debugging.

The computer software is being developed using the APL-developed universal cross assembler package on the IBM 360/91. The computer and power supply have been assembled and all peripherals (display, A/D, D/A) have been interfaced. The software has been written and checked out for those peripherals. Initial tests with the computer driving the manipulator should commence during February 1977. The complete manipulator system is expected to be in clinical testing by late Spring 1977.

Manipulator Unit for VA Hospital, West Roxbury, Massachusetts

On November 10, 1976, a prototype manipulator/work table system was delivered to the VAH, West Roxbury, and its operation demonstrated to members of the VAH staff. It is hoped that clinical testing will include a large number and variety of subjects in order to extend the manipulator's functional capability and task applicability to meet the needs and desires of as wide a range of subjects as possible. Clinical evaluation protocol is being developed and subject evaluation is expected to commence early in 1977.

Continued Evaluation of Externally Powered Upper-Limb Prostheses

Clinical followup is continuing on externally powered upper-limb prosthetic systems previously developed under this program. Of the 15 experimental prostheses fitted to 13 amputees between January 1970 and January 1974, 2 are still in daily functional use and are considered by the users as essential in their vocational or avocational activities; one is now 6 years, the other 4½ years after original fitting.

Over 43 man-years of in-use field trial test time have now been accumulated with these 15 experimental prostheses.

Four of the 15 prostheses are retained by the users for occasional use—merely for cosmesis or to assist in some uncommon but necessary bimanual activity. Therefore, these four are no longer counted in the total accumulated field test time. Of the remaining nine units, one above-elbow prosthesis has been recently modified to provide live lift capability to avoid dropping objects during elbow flexion. This unit is being returned to the test subject for further field evaluation. Six of the 15 units were returned after being in regular use for periods in excess of 1 year. They were returned due to a variety of factors, as reported in BPR 10-25.

The remaining two were barely used at all and were retrieved within a few months of delivery. These two were fitted early in the program while subject selection criteria were relatively unrefined and the electrical power and control units were less satisfactory.

Development and Evaluation of Advanced Automotive Adaptive Equipment[a]

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Make McDermott, Jr., Ph. D., and Lewis A. Leavitt, M.D.

Introduction

The basic intent of this project has been to develop and evaluate automotive adaptive equipment to meet the needs of those disabled who are not served by currently available standard automotive equipment. This effort required solution to the problems of entry/exit, seating/restraint, driver control systems, and additional safety features, so that persons with low levels of physical functional ability (e.g., quadriplegics) could attain a measure of mobility by way of independent automotive transportation. Included in the plan of work were:

1. Analytical efforts in the areas of human engineering and systems safety;
2. Evaluation and testing efforts on new equipment rapidly becoming available, such as wheelchair lifts and restraints, and servo and secondary control driving systems;
3. Development of official government standards for the various types of adaptive equipment.

I. Wheelchair Lifts

A test plan was developed for the orderly and standardized evaluation of all available wheelchair lifts. This evaluation was based on—

1. The ability of a lift to be installed and operated according to the manufacturer's instructions and claims;
2. Adherence to accepted engineering design and fabrication practices;
3. Systems' safety features and shortcomings;

[a]This summary covers the period July 1, 1975, to November 30, 1976, under VA contract V101(134)P-335.

4. Identification of potential user errors and possible results; and
5. Ease and convenience of use by handicapped users having various capabilities.

The evaluation[b] involved the following methods: 1. Engineering evaluations of the design and fabrication aspects of the lifts; 2. Physical measurements of the lifts (length, width, height, and angular dimensions); 3. Acceleration measurements of the lift platforms during the various modes of operation; 4. Assessment of load lifting capacity; 5. Evaluation of noise levels of the lift drive units; 6. Evaluation of lift actuating controls; 7. Evaluation of occupant actions, errors, and hazards; and 8. Accelerated lift cycle testing. The evaluations were done by the engineers and technicians assigned to the project, but also four quadriplegics were utilized in the evaluation of occupant actions, errors and hazards.

The following lifts were evaluated:

1. Braun Corp., 1014 S. Monticello, Winamac, IN 46996
2. Casady Safety Van Lift, 1627 Linnea Ave., Eugene, OR 97401
3. Collins Industries, P.O. Box 58, Hutchinson, KS 67501
4. Compass Industries, Inc., 715 15th St., Hermosa Beach, CA 90254
5. Helper Industries, Inc., 832 N.W. 1st St., Ft. Lauderdale, FL 33311
6. Maxon Industries, Inc., 1960 E. Slauson Ave., Huntington Park, CA 90255
7. Para Industries, Ltd., #6-4826-11th St., N.E., Calgary, Alberta, Canada
8. Ricon Corp., 15806 Arminta St., Van Nuys, CA 91406
9. Speedy Wagon Sales Corp., 2237 Harvester Road, St. Charles, MO 63301

The results of the evaluations of each of the above lifts were reported to the Veterans Administration in "An Evaluation of Commercially Available Wheelchair Lift Devices," November 20, 1975 (revised April 1976) by Duncan, Dean D. and McDermott, Make, Jr.

During the contract period, a first draft of a standard for lifts was prepared. The draft standard was based on information gathered from the evaluations, and from existing applicable industry standards such as those from the American National Standards Institute and the Society of Automotive Engineers. A rationale was

[b]The evaluations developed a comprehensive body of knowledge on wheelchair lifts from nine different manufacturers, and a data base for use in developing a standard for wheelchair lifts.

presented for each of the various requirements of the standard.

The wheelchair lift industry is a rapidly changing one. There are known to be some 20 to 25 different nationally advertised companies which manufacture and/or sell wheelchair lifts of a variety of designs. Some devices seemed to have been designed, fabricated, and then marketed with a minimum of test and evaluation on the part of the manufacturer—this is especially true with the newer companies. Many of the design/use deficiencies discovered during this evaluation program have already been corrected on later models of the lifts.

II. Testing and Evaluation of Driver Control Systems

The purpose of this program is to test items of advanced adaptive equipment to determine their effects on system performance and safety. The testing goes beyond the low-speed testing normally done during driver licensing tests in order to provide a more meaningful evaluation of these untried systems' safety. The tests involve the following regimes:

1. Long-term use—2000 miles under simulated urban and rural road conditions;
2. Low-speed maneuvers—a "driver training" course;
3. High-speed and emergency maneuvers—obstacle avoidance, braking, and curve negotiation.

The test program is complemented by a human factors (ergonomics) evaluation, a safety evaluation, and a failure-mode-effect analysis. Initial test operations involve a professional test driver and a driver drawn from the general driving population. Neither of these individuals is physically handicapped. Parts of the test are then repeated with spinal-cord-injured veterans (C-6/7 or higher lesion quadriplegics). The test protocol has the following specific purposes and objectives.

(From the Test Plan—)

Purpose

The purpose of this test is to conduct an integrated and comprehensive evaluation of an adaptive control setup installed and operative in a motor vehicle.

The test protocol will comprise preliminary configuration checks, a human factors and safety evaluation of the control devices in place in the motor vehicle, and a composite 2000 mile road test. The road test will simulate the range of highway operating conditions that might be expected to be encountered by a handicapped driver.

Objectives

This test has the following specific objectives:

(1) Assess the operability and workspace envelope of a candidate adaptive control system as installed in a motor vehicle.

(2) Assess the feasibility of the control system as an adaptive system prior to road use.

(3) Conduct a simulated highway use test comprising 2000 miles to determine long-term operability and the effects of the control system on vehicle handling.

The principal measurement made in the driving tests is the comparison of the vehicle and driver's performance as equipped with the adaptive control system vs. that performance attainable using the original equipment control system in the same or similar vehicle. Most of the performance data are in the form of trials to criterion, time to perform a maneuver, hits/misses or other variant of this, plus a rating by a qualified test conductor on an ordinal scale basis.

All test runs are made under the standard checkout and safety rules prescribed in the Test Plan, and are under the direct control of a Test Conductor designated by the project Co-Principal Investigators.

Work Accomplished in Contract Year

Three vehicles equipped with unconventional control systems have undergone testing during the contract year:

1. Harden-CCI (Creative Controls Inc.) Mode I throttle/brake servocontrol system.
2. Mobility Engineering and Development, Inc. (MEDI, Charles Scott).
3. Sevier Van (James Allen).

None of these installations was without deficiencies. These were reported to the developers for correction or re-design, etc.

The test plan is to compare road tests, vehicle evaluations, and handicapped driver performance evaluations with advanced servocontrol systems which have been debugged and which provide an objective framework for assessing the potential of other systems to assist disabled veterans to drive. We now have a standard routine for testing any control system which may be submitted to the VA for approval, and this routine provides the basis for a servocontrol system standard which must eventually be drafted.

III. Testing and Evaluation of Wheelchair Restraints

An effort was initiated during the current contract year to evaluate several commercially available wheelchair restraints designed for use by wheelchair-bound drivers or passengers. To this end a "Wheelchair Restraint Systems Test Plan Outline" dated June 1976 was written and submitted to VAPC. The objective of the testing was to determine the capability of commercially available wheelchair restraint systems for holding the wheelchair and occupant in place during vehicle motion. Specifically, the test plan considers the following:

1. Does the restraint accomplish its stated purpose?
2. Was good design and fabrication practice followed?
3. Actions and/or decisions required of the occupant and/or the attendant.
4. Possible errors by occupant and/or attendant.
5. Movement of wheelchair for forces from 0g to 1g (range of forces normally encountered during driving).
6. Movement, permanent deformations, and failures for load greater than 1g.

Seven restraint systems were purchased and tested and the following conclusions were reached. First: the wheelchair occupant should be restrained directly to the motor vehicle carrying the wheelchair, and not to the wheelchair. Second: do not clamp only the rear wheels of the wheelchair to the floor of the vehicle—if the wheels are so locked, then additional restraints must also be employed. And third: some types of restraints are not capable of withstanding longitudinal and/or transverse static loads equivalent to those imposed by the combined mass of the anthropometric dummy and wheelchair (274 lb) under accelerations likely to occur during normal (noncollision) driving conditions.

The ultimate goal of this project is to determine a set of requirements which restraint equipment must satisfy in order to be safe and of reasonable quality. The VA can then use these requirements in its standards program for prosthetics, orthotics, and orthopedic aids.

IV. Miscellaneous Activities

In the course of this year's activity a certain amount of effort has been expended in development of several concepts that contribute to our understanding of a handicapped driver's capability, or that provide guidelines to prospective designers of hardware to support the quadriplegic and other severely handicapped patients. This developmental effort has been low-priority, but fruitful in these three different areas:

1. *Driver Evaluation Device*–A special measurement device which can be used to measure the force capabilities of handicapped patients (and directly applied for prescriptive purposes) has been designed and built. The unit clamps to a table top and features a steering wheel which can be positioned to the approximate angle of tilt of a van or ordinary passenger car. The wheel is attached to a spring scale to measure static forces exerted by the patient while he holds the wheel. Both direction of force and hand position (or spinner position) can be varied.

Hand control force levels can be measured using this device. The forces are measured by means of an ordinary torque wrench which can be positioned to approximate any of the available hand-control input motions.

Two units have been built. One is in our laboratory at College Station, the other is in Houston at TIRR where it is being used by the occupational therapy group. This effort was documented in the report "Texas A&M Handicapped Driver Evaluation" dated August 1976.

2. *Wheelchair Restraint*–The wheelchair restraint system has been dubbed the "CLAMP" (Carrier Lock Automatic Mechanism for 'Plegics'). This unit can be mounted either on an electric wheelchair or on the floor of a vehicle. Two screwlock-operated claws engage a straight rod to provide positive two-point attachment of the chair to the vehicle. Lateral and angular displacement are minimized. It is worth noting that we have integrated a lap belt into the CLAMP-type wheelchair restraint in such a way that *the patient is tied through the restraint gear into the vehicle structure* rather than to the wheelchair itself.

3. *Secondary Controls Panel*–The Human Factors Group of TTI has also gone through a developmental design exercise on configuring a special panel for quadriplegics. The panel replaces or supplements the standard vehicle instrument panel. The panel or console is "lap mounted" and has controls and displays for gear position, lighting, turn and hazard signals, parking brake operation, horn, wipers, washers, and ignition/start.

The panel has been mocked up, and will be translated into a working prototype in the next period of activity in support of the Secondary Control System evaluation effort. This effort was documented in the report "Conceptual Design of an Adaptive Secondary Control System Panel" dated March 1976.

Control of an Artificial Upper Limb in Several Degrees of Freedom

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During the second half of 1976 the main emphasis of this work was, as in the preceding 6 month period, on the EMG controlled prosthesis. Specifically, work has continued on speeding up the microcomputer algorithm such that limb actuation can be accomplished within the required 0.15 to 0.2 s, using our EMG identification and recognition algorithm (1,2) on an Intel 8 Mod 80 microcomputer system in real time and with double precision (i.e., with 16-bit words instead of the standard 8-bit words). Another major aspect of the work during the period covered by this report was concerned with enhancement of reliability of the system, noting that such enhancement requires additional computation and, therefore, the solution of the computational speeding-up problem is a prerequisite to the reliability enhancement problem. Finally, amputee tests were performed during the period to check speed and reliability in real time and with real microprocessor hardware.

Concerning the enhancement of computational speed, further work was done on our parallel filtering algorithm (2) which facilitates limb actuation during normal usage without continuous re-identification, so that the lengthy identification algorithm is called for only at the calibration mode. This work has led to the overcoming of previous identification biases occurring with parallel filtering, by the use of certain modifications of the algorithm which followed theoretical studies. When these modifications were completed, they resulted in an algorithm which not only met the speed requirements for actuation within 0.15 to 0.2 s, but that also outperformed, in terms of both actuation accuracy (reliability) and speed, all other speeded-up algorithms of our basic version. This is indicated by Table 1, which gives results of actual on-line microcomputer amputee tests.

Observing Table 1, it is obvious that further enhancement of reliability could be expected by increasing the number of AR (autoregressive) model parameters from 3 to 4 (compare, say, experiments No. 3 and No. 6 in Table 1 where only the number of AR parameters is different). Consequently, work has been initiated on rewriting the algorithm of experiments No. 7 and No. 8 of Table 1 for 4 AR parameters. It is noted that this modification affects only the Calibration mode (in terms of computational speed), so no additional actuation delay should result.

TABLE 1.—*Amputee Tests (Performed on Intel 8 Mod 80 Microcomputer at Double Precision) 1976*

Experiment number	Identifier	Length of data record	Reference parameters	Number of functions considered	Function discrimination	Approx. accuracy	Actuation delay (sec.)
1	Seq. least Sq.	200	3 AR + Var.	4	Vector space	85%	1.3
2	Seq. least Sq.	200	3 AR + Var.	3	Vector space	95%	1.3
3	Gradient Desc.	200	3 AR	3	Vector space	65%	0.25
4	Gradient Desc.	400	3 AR	4	Vector space	65%	0.30
5	Gradient Desc.	400	3 AR + Var.	3	Vector space	85%	0.30
6	Gradient Desc.	400	4 AR	4	Vector space	70%	0.35
7	Seq. least Sq.	400	3 AR	2	Parallel filtering	85%	0.15
8	Seq. least Sq.	400	3 AR	4	Parallel filtering	80%	0.20

Further speed enhancement is expected when the newly acquired hardware multiplier system, which is also of a longer word length, is finally incorporated. (This incorporation was delayed due to malfunction of interface hardware.)

Therefore, although the basic speed and accuracy requirements have already been met, further enhancements are expected during the next phase of our work when the new 4-parameter algorithm is complete and when the new hardware multiplier is operational. This will permit introduction of the now-missing speed control, which requires additional computation (and thus additional computational delay, not tolerable presently) and an additional load on the discrimination algorithm (not tolerable so far, due to effects on accuracy). Obviously, with additional improvements in speed and in reliability, objections to speed control should no longer be valid.

It is important to note that a further speeding-up of computation, and therefore further enhancement in reliability (reliability being linked to computational speed since higher reliability implies that more parameters are to be identified, and thus, longer computation), is possible when faster microprocessor systems are used. Such systems are now available (MIPROC 8, etc.), but were not available when our Intel 8 Mod 80 microcomputer system was purchased for this project.

Furthermore, all conclusions derived from this work are fully and directly applicable to any other microprocessor hardware. Hence, the changing of the hardware is not recommended, especially when considering the very dynamic microprocessor hardware market where last month's hardware is considerably surpassed by this month's.

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Acceleration of Bone Healing by Electrical Stimulation

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During the previous contract period at St. Luke's Hospital, a model for a stable non-union in canine bone (ulna) was developed and initial trials of electrical stimulation by pulsed and continuous

currents were conducted. This study, reported elsewhere in detail,[a] was the first to be initiated as an attempt to create bony healing over a large (2cm) defect in a long bone.

Although only partially successful in its primary aim, the prior investigation highlighted several important questions concerning electrical stimulation of bone healing. A method for determining presence of bone formation by means of electrical impedance measurements also was developed.

Work under the present contract, recently begun at VAH, Castle Point, will extend the prior study to determine the relative importance of current density, current characteristics during the "off" segment of pulsed stimulation, and electrode position in relation to pre-existing bone or marrow as factors in facilitating a stimulatory response adequate to produce clinically significant bone healing of large osseus defects.

Hemodynamic Evaluation of Postoperative and Preoperative Amputees

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During the 6 month period, 48 new patients with peripheral vascular disease and three patients who had been followed over a period of 5 to 10 yr were admitted to the Surgical Service. Immediately after admission, each patient was evaluated in the Vascular Clinic-Laboratory where patients were given a battery of tests designed to assess their vascular status. On the basis of results obtained from Doppler pressure studies, skin surface temperature, arterial and venous impedance plethysmography, noninvasive electromagnetic flowmetry, and arteriography and venography when indicated, the appropriate treatment of the patient was determined.

Thirteen of the patients had lumbar sympathectomy procedure. All of these reported relief of their symptoms and are being followed in the Vascular Clinic-Laboratory. Three of the 13 patients had had impending gangrene which disappeared following sympathectomy.

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[a]Cochran, G.V.B., Derman, R.M., and Palmieri, V.: Determination of Effects of Electrical Stimulation on Healing of an Experimental Model for Non-Union in Canine Bone, P13.9 Proc. 29th A.C.E.M.B., Boston, Massachusetts, November 6-10, 1976.

The three long-term followup patients included—

1. An elderly male with diffuse arteriosclerotic occlusive disease and an above-knee amputation, who had returned to the clinic for revision of the stump;
2. A 55-yr-old man who 7 yrs ago had a sympathectomy and a thromboendarterectomy procedure performed for impending gangrene. This was still quite suitable; however, the contralateral side now showed progression of the arterial disease. A lumbar sympathectomy relieved his present symptoms.
3. A 58-yr-old diabetic with arteriosclerotic occlusive disease who had had a lumbar sympathectomy and femoropopliteal bypass graft 5 yr earlier; he returned to the clinic with a true aneurysm of the graft. This graft was replaced with the new umbilical vein graft procedure.

For two severely involved patients with arteriosclerotic occlusive disease and gangrene, the only choice was amputation above the knee. One other patient presented with toxic gangrene of the foot; following vascular tests a long below-knee amputation was performed. The patient is now using a prosthesis.

A 55-yr-old male was admitted to the clinic with superficial gangrene of the toes of one foot secondary to peripheral vascular disease. Gangrene was precipitated by exposure to severe cold and resultant frostbite. A lumbar sympathectomy was performed and within a few months only the tips of two toes were lost. The patient left the hospital with both limbs and is ambulating well.

An 85-yr-old male was admitted with arteriosclerotic occlusive disease and bilateral popliteal aneurysm. Unilateral severe deep venous thrombosis was detected and the same limb showed severe black discoloration over the anterior portion of the foot. With appropriate anticoagulation and repair of the bilateral aneurysms, which restored pulsatile flow to the lower limbs, amputation of the toes was necessary on one foot only. The patient is home and ambulating well.

Of five new patients with severe ischemic pain at rest, all had lumbar sympathectomy and a bypass procedure:

1. A 60-yr-old male had a successful bilateral femoropopliteal bypass and has returned to work;
2. A 65-yr-old male had a successful axillo-femoral bypass but is deceased following a myocardial infarct;
3. A 72-yr-old male with severe arteriosclerotic occlusive disease had a good response to lumbar sympathectomy (however, his axillo-femoral bypass graft did not function);

4. A 59-yr-old male with severe arteriosclerotic occlusive disease had a bilateral sympathectomy. Because of poor runoff, the bilateral bypass procedure could not be performed and the patient is now a bilateral below-knee amputee.

5. A 52-yr-old male did not have relief of his pain following lumbar sympathectomy; tests completed in the Vascular Laboratory showed further progression of disease and the patient is now a candidate for aorto-femoral bypass graft procedure.

One 52-yr-old male with a 30 yr history of diabetes sustained an injury to one foot which subsequently developed into gangrene. Upon his arrival in the hospital, tests showed advanced small-vessel changes and severe arteriosclerotic occlusive disease. With control of the diabetes, the patient first had a lumbar sympathectomy; this was followed by an axillo-femoral-popliteal bypass with ultimate healing of the big toe and heel. The patient is ambulating well and has returned to an active life at home.

Three remaining patients each presented with a special vascular problem. The first was a 60-yr-old male with an abdominal aortic aneurysm. During his surgical procedure the Doppler instrument was used to assess the status of blood flow in the mesenteric artery, thus providing information as to the viability of the intestine. The second patient had a subclavian aneurysm and peripheral embolism causing ischemic symptoms in the hand: the aneurysm was resected and the embolism removed with restoration of blood flow to the hand. The third patient had had a cerebral vascular accident; he presented with impending gangrene of the paralyzed lower limb. Delayed thrombectomy salvaged his limb.

The 12 remaining patients all had venous disease. Use of the venous impedance plethysmographic test detected the presence of deep vein thrombosis which was then confirmed by venography. Appropriate anticoagulant therapy was then instituted and during treatment the patient's daily progress was monitored using thromboelastography and impedance plethysmography.

For every instance cited in this report, the decision for appropriate treatment of the patient was determined by the tests completed in the Vascular Clinic-Laboratory. During this 6-month period 740 patients were seen in the laboratory representing approximately 1075 test procedures. This 6-month experience again reinforces three important issues:

1. Patients must be encouraged to pay attention to their signs and symptoms and to seek help early when more can be done to alleviate a problem;
2. The vascular test procedures used in the laboratory provide the

surgeon with the necessary information for accurate treatment. This leads to quality patient care; and

3. Once a patient has had care he must continue to return to the Clinic-Laboratory for followup.

Maxillofacial Restorative Materials and Techniques
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Cosmetic realism in facial prostheses is an indispensible feature of reconstruction for acceptance by the individual as a pleasing, unnoticeable replacement of the missing facial component. It ranks equally in importance with tactile quality of feel and compliance, which have to replicate as nearly as possible those of living skin and tissue (1).

Cosmetic matching is usually carried out as a skilled art highly dependent upon the subjective judgment of the artists, not without controversy over some of the nuances of visual sensation or response. However, to assure a uniform duplicative standardization, such as that currently being done in the replication of the stress-strain tensile profile, there is need for quantitative standardization of visual coloration in strict comparison and replication of the human skin and living tissue. Such standardization requires spectral measurements (2). It has therefore been the object of this study to determine and apply quantitative numerical constants for the natural pigmentation of skin and living tissue, the intrinsic coloration due to hemoglobins, melanin, and carotene, to be duplicated by substituted, artificial, commercially standardized pigments. This concept and approach, while obvious and implicitly necessary, has not been approached in this manner according to any disclosure in the published literature.

To duplicate or approximate the natural, intrinsic, sub-dermal pigmentation in its dispersive, aggregative, and reticulated form as venoarterioles, lipoglobules, etc., the procedure has been to measure the principal spectral reflections. This can be done either by continuous-line spectrophotometry (General Electric system) or by the separative, digital color difference (DCD) system devised by Hunterlab. The former has been utilized extensively in color analyses but provides only a graphic reading which it is impractical, generally, to express numerically as would be needed for commercial and other specifications. The Hunter DCD system, giving measurements in

numbers, adapts itself conveniently and preferentially for this study as it has for the quality control and identification of textiles, paper, paints, and even facepowders. The Hunter DCD system measures the total reflection (L); the red (+) versus green (−) as the (a) index; and the yellow (+) versus the blue (−) as the (b) index. With the numerical indices, the red (a) indicates the reflective intensity of the hemoglobin components in the skin and tissues, while the yellow reflective intensity accounts for the reflectance of the natural carotene, the principal subdermal pigments (along with melanin) which are to be replicated for the intrinsic coloration of facial prosthesis. The topical or extrinsic matching, along with characteristic skin blotches, can be applied by the artist-prosthetist, or through the application by the individual of an appropriately matched face powder.

Digital Color Difference Indices of Human Skin

Table 2 summarizes the measured DCD indices for reflectance (L), and for the red/green (±a) and the yellow/blue (±b) indices, along with the corresponding ratios to indicate dominance of the red (a/b) or dominance of the yellow (b/a) in visual sensations. Included also in Table 2 are DCD indices obtained with cosmetic hand swatches (from Number 4 to 16), which reveal considerable

TABLE 2.—*Hunterlab DCD Indices Measured with Human Skin (Dorsal)*

Substrate		Colorimeter Measurements				
		Reflectance (L)	(a)	(b)	(a)/(b) Ratio[a]	(b)/(a) Ratio[a]
Human skin						
Caucasian	Lightest	50.1	+ 2.2	+ 10.4	0.22	4.73
	Darkest	59.9	+ 8.6	+ 14.8	0.58	1.72
Negroid	Lightest	44.7	+ 9.4	+ 17.1	0.55	1.82
	Darkest	48.2	+ 10.2	+ 17.4	0.59	1.71
Cosmetic Hand Swatches (from Number 4 to 16)						
	Lightest	44.1	+ 4.6	+ 13.3	0.35	2.89
	Darkest	66.2	+ 9.9	+ 18.7	0.53	1.89

[a]The (a)/(b) ratio provides an indication of the dominance, or more pertinently the subdominant intensity, of the redness, such that when the ratio reaches 1.0 the two color sensations are in equal mono-spectral intensity. Conversely this applies to the yellowness with the (b)/(a) ratio. The mono-spectral intensity is preserved as the pure colorants related to the hemoglobin and the carotene components of living skin and its under (subdermal) layers.

discrepancy from the readings obtained with human skin of both races. In terms of the (a)/(b) and the (b)/(a) ratios, the Hunter DCD indices reveal also a marked difference between the Caucasian and the Negroid races, the latter having a higher redness factor presumably due to the fractional spectra in this direction contributed by the natural melanin.

Digital Color Difference Measurements for Artificial Pigments

Following the criteria of skin coloration already described, a series of commercial reds and yellows are being formulated with the standard polysiloxane (silicone) prosthesis formulation (1) in the form of concentrates containing precise amount of the pigments, from which intrinsically pigmented stocks can be prepared for making the prosthesis. Currently, these stocks are pigmented to accommodate two levels of intrinsic colorations for each of the two races. The intrinsic colorations are selected to provide from 60 to 80 percent of the DCD indices. The final extrinsic or topical coloration can be applied by the artist or prosthetist to match the individual's skin adjacent to the prosthesis.

TABLE 3.—*Selected Candidate Pigments for Intrinsic, Stable (3), Facial Prostheses*

Pigment	Industrial Identification	Hunter DCD Indices[a]		
		Redness + (a)	Yellowness + (b)	(a)/(b) Ratio
Red Group (partial, selected)				
Monastral Red	RT-759-D	44.9	12.4	3.62
Monastral Pink	RT-215-D	36.6	10.5	3.49
Magico Iron Oxide Red[b]	L-205-CS	34.2	17.4	1.97
Monastral Maroon	RT-792-D	28.3	12.4	2.28
Red Rayon Floc (1/32″)	(Claremont)	5.8	9.8	0.59
Yellow Group (partial, selected)				
Monastral Gold	YT-823-D	18.8	18.4	1.02
Magico Iron Oxide Brown[b]	422 L-71174	20.7	16.8	1.23
Yellow Oxide (Pfizer)[b]	YO-3087	14.8	34.4	0.43
Yellow Ochre (Winsor & Newton)		(1)	25.9	0.04
Carotene (Sigma Chemical)		10.6	16.1	0.66
Melanin (Sigma Chemical)		2.8	7.3	0.38

[a]Digital Color Differences (Hunterlab)

[b]Reasonably stable to acidic exposure but may be severely discolored by hygienic cleansing agents such as are used for dentures (Efferdent) or in laundry (Clorox), etc. The iron oxides may turn to ferric chloride which is intensely green (-a) and may give an undesirable, non-living coloration.

Presently, the concentrates are formulated to 10 percent pigment level as is done in industrial practice of coloring plastics and elastomers. For pigment-standardization measurements for the DCD indices, the concentrate is further processed at a level of 0.10 percent concentrate, which ultimately brings the precise pigment level to 0.01 percent level. Table 3 summarizes a select group of the two most prominant colorants, namely the red and the yellow, processed from the concentrate to the 0.01 percent level, which was accorded the designation as stock material for the intrinsically pigmented prosthesis.

The measurements of the digital color differences indicate an almost uniform, stepwise gradation from redness to yellowness, thereby providing a quantitative index for any one of the pigments for a combination that can be, by an appropriate calculation, formulated into a concentrate for use in making the stock material. This is precisely the manner by which the intrinsically colored prostheses are being made for a preference study now under way. The data in Table 2 point out that a high (a)/(b) red pigment and a low (a)/(b) yellow pigment should more nearly approximate the existing natural pigments in the skin, namely hemoglobin and carotene, respectively. It is surprising to note that carotene and melanin (the third principal component pigment in skin and living tissue) while nominally considered yellow and brown, actually show an appreciable amount of the spectral red reflectance.

This method of determining the DCD indices in processed concentrates and stocks is a continuing feature of this program, supplemented by projected investigations of intrinsic dispersion of the spectral indices using titania blended with the concentrate and hence the stock.

In view of the complex variations in the refractive properties of the physiological components in the skin and especially the tissues, this effort also includes the addition of organic modifiers, in this case polyisobutylene, which has an index of refraction differing from that of polysiloxane. Polyisobutylene is being studied as a tackifying agent to retain extrinsic colorations even by the simple powdering of cosmetic facial powders.

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Permanently Attached Artificial Limbs

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Introduction

Over the past several years, numerous designs of a permanently attached artificial limb have been designed for placement on the amputated tibia of Spanish goats. Criteria for future designs have been selected from past successes and failures and have been previously enumerated. (See BPR 10-25, pp 69-96, Spring 1976). To date, we have little to add to these criteria, with the possible exception of the method for skin penetration which is the subject of this report.

Previous reports have dealt with various methods for attaching the endoprosthesis to the bone; i.e., intramedullary, supracortical, and supraperiosteal (Fig. 13). Each of these methods used a direct skin-penetrating member coated with one of the skin-interfacing materials. Regardless of what material had been used for skin interfacing, the results eventually terminated in the skin retracting beyond the reach of the skin interfacing material. Best results had been obtained using nylon or Dacron velour as the skin interfacing material, and we had blamed the "growth phenomenon" for the eventual failure of these materials.

Briefly stated, the "growth phenomenon" of this theory is seen when a velour-covered skin-penetrating device has been implanted for several weeks or months. As healing occurs, basal cells attach themselves to the monofilament fibers of the velour. The physical-chemical attraction of each cell's protein surface appears sufficient to keep it at a particular locus on the fiber's surface. As the basal cell matures, it migrates toward the skin's surface—carrying with it the monofilament fiber. Since all the basal cells at a specific depth from the surface have approximately the same rate of maturation, a vector force is continually pulling the velour-covered device toward the surface. This causes the device to literally "grow" like hair, nails, etc. Hence, the term, "growth phenomenon."

A more critical evaluation disclosed that an elastic membrane covering a cylindrical object should have the membrane intact over the end of the cylinder. If a hole were placed in the membrane at

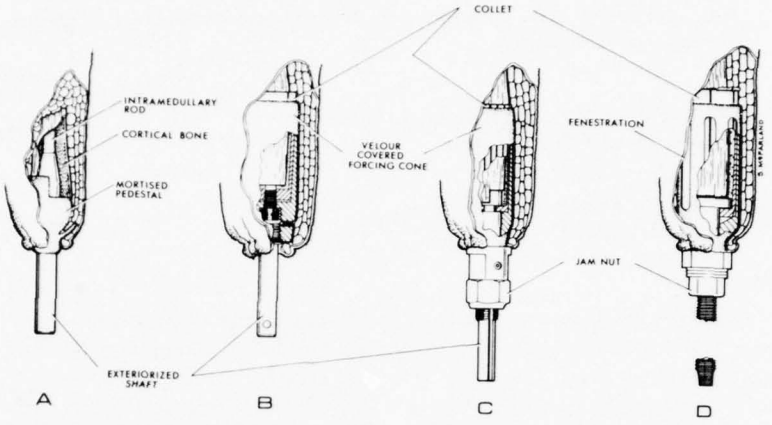

FIGURE 13.—The transition of the intramedullary rod to a supracortical and later to a supraperiosteal interfacing is shown in the above line drawing. All use a simple pylon exiting directly to the exterior. The intramedullary (A) method used a rod coated with such materials as *porous alumina*, *porous polymethylmethacrylate*, sandblasted stainless steel, sandblasted Vitallium® and stainless steel with bone cement. A morticed pedestal coated with nylon velour bonded to the intramedullary rod serves to stabilize the long axis against forces of torque and to anchor the skin through which it penetrates.

B, C, and D are similar, in that each has collets compressing either cortical bone directly or periosteum through a layer of interposed elastomer. A velour-covered forcing cone driven by a jam nut causes the forcing cone to compress the collets.

the end of the supporting structure (in this case, bone and the attached endoprosthesis), the elastic membrane retracts, allowing the supporting structure to protrude. Most surgeons have on occasion been witness to this when putting on a rubber glove with a small hole in the tip of one of the glove's fingers and having the surgeon's finger suddenly appear through the glove's fingertip.

It finally became apparent from these consistent failures that, no matter what interfacing material was to be used, the skin over the amputated stump's end should be left intact. This, of course, leaves one with a new problem, which is how to transfer the skeletal load to the exterior without going through intervening soft tissues (which would violate our first criterion for the development of a permanently attached artificial limb).

The Involuted Approach—A New Method for Percutaneous Skeletal Attachment

Adoption of the idea of closing the amputated end of the stump and yet transferring the skeletal load to the exterior dictated an

indirect approach. Placing the end of the bone in a basket or bucket supported at the lip by lugs would allow such a load transfer, provided that the lugs penetrated the skin some distance proximal to the stump's end and could be appropriately attached to an external pylon. Tracing the transmission of forces from the bone's shaft to the bottom of the bucket, then up the walls of the bucket to the lugs, and then down the pylon to the ground, shows the reasoning behind selection of the term "involuted."

Figure 14 shows the evolutionary development of this approach. A stainless steel basket having an elastomer inner liner allowed a "quick and dirty" look at this radical departure from the direct approach. Figure 15 demonstrates the surgical technique used for the current model. A trifurcated pylon is later bolted to the penetrating lugs.

The current model is an attempt toward simplification, both in fabrication and surgical placement of the device. Bone cement is currently being used to bond the bucket to the end of the tibia. To strengthen the surface adhesion, "pores" were made in the cortical surface using an alligator clamp.

Results

To date, seven of the stainless steel bucket devices have been implanted. Although all are surviving without apparent problems, it is too early to predict the ultimate fate of this method.

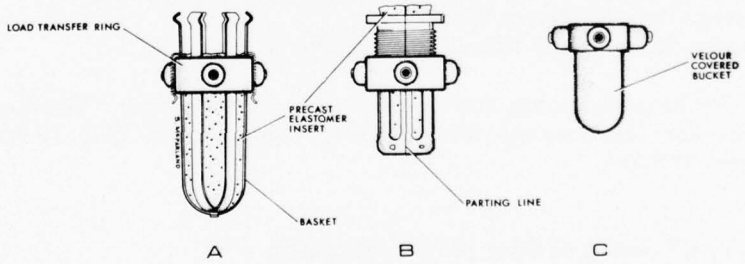

FIGURE 14.—Transition from the "quick and dirty" experiment using the "basket" approach (A), to the sophisticated but rather bulky supraperiosteal "clam shell" (B), to the simple stainless steel bucket (C) is depicted in the artist's drawings. Each of the above is an example of the indirect or involuted method of coming through the integument.

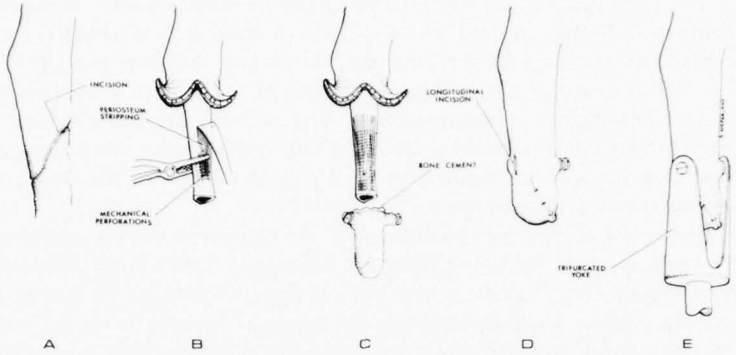

FIGURE 15.—(A). Simple below-knee amputation of the right hind limb of a Spanish goat inaugurates the indirect approach for direct skeletal attachment of a percutaneous endoprosthesis. After stripping the periosteum (B), the bone is mechanically perforated to enhance adhesion of the bone cement and rigidity of the bucket (C). Skin closure over the end of the bucket is similar to closure of any amputated stump. Small longitudinal skin incisions (D) expose the screw head for placement of the trifurcated yoke pylon (E).

Mobility Aids for the Severely Handicapped
Mobility Engineering and Development (MED), Inc.
6905 Shoup Avenue
Canoga Park, California 91306
Charles M. Scott and Ronald E. Prior, Ph. D.

For Progress during this report period, see the article, "Mobility Aids for the Severely Handicapped," appearing in BPR 10-26, pages 392-433.

In Vivo Loading of Knee Joint Replacement
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No progress report was submitted by this contractor for this report period.

Research and Development Project on Advanced Orthotic Devices for Adult Paraplegics

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The PACO Concept

The PACO, an acronym for Pivot Ambulating Crutchless Orthosis, is designed to be one component of a complete mobility system for adult paraplegics. For short distances (50 m), the PACO unit provides mobility and upright support. To travel up to 1 km, a conventional wheelchair is an efficient, practical solution, while longer trips would necessitate a motorized vehicle (automobile or bus). The goals of the PACO system are to provide—

1. support and balance in an upright position without use of hands;
2. limited ambulation in the upright position;
3. unaided standing and sitting;
4. compatibility with wheelchairs;
5. a device that is easy to don and doff; and
6. easily adjusted by an orthotist for various patients.

The PACO concept was inspired by the 1970 development of the "Parapodium" for children at the Ontario Children's Centre by Wallace Motloch, who also developed the pivot walk method of forward locomotion. Pivot ambulation accomplishes forward locomotion through successive body rotations about vertical axes lateral to the feet (Fig. 16). The related swivel walking utilizes basically the same concept, with the soles of the feet being the respective points of rotation. In either case, the amount of forward progression with each step is a function of the lateral spacing between pivots and the angle of rotation.

Present State of Effort

PACO III was designed to retain the advantages of PACO II while satisfying all of the stated design goals. The first step toward independent standing was the design of wheelchair armrests which can be turned around so that they project forward of the chair. Tele-

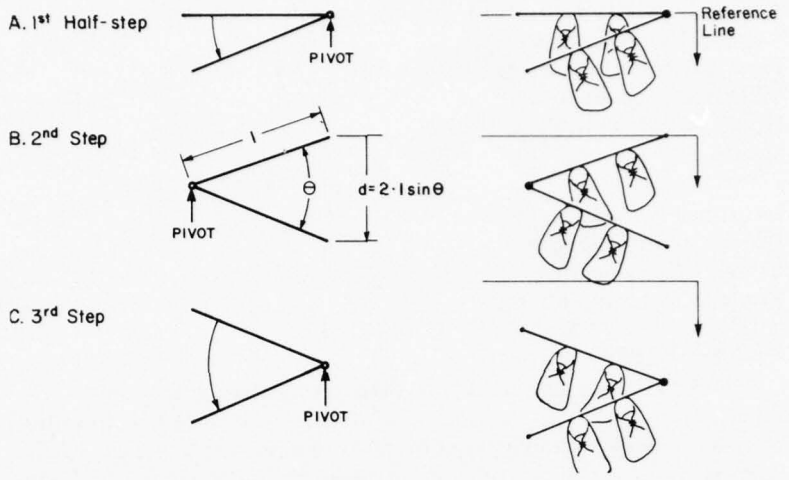

FIGURE 16.—Pivot ambulation: forward progression by alternating rotations about two lateral points.

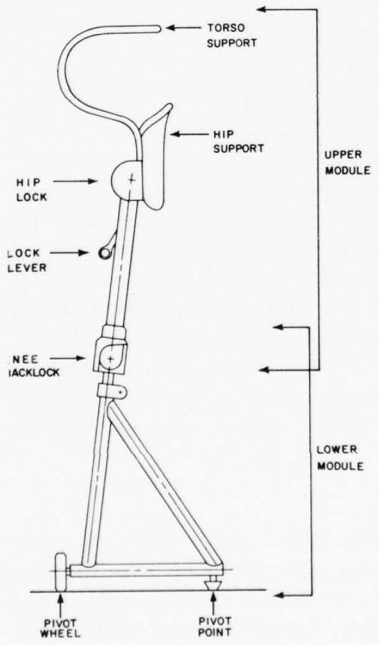

FIGURE 17.—Lateral schematic view of PACO III.

scoping tubes are then lowered to the floor to prevent tipping forward and the armrests are raised up as much as 40 cm. The result is a pair of stable parallel bars attached to the wheelchair.

Like its predecessor, PACO III (Fig. 17) has upper and lower modules for easier donning and doffing while seated in the wheelchair. The lower module is, in essence, a triangular structure. Telescoping tubes allow adjustment for knee-to-ankle length. Knee locks on the upper module slide onto the hexagonal studs located at the knees of the lower module, as a socket wrench slides onto a nut. The knee locks employ a cable-wrapped capstan which, when engaged, allows knee extension but not flexion. When he is standing, therefore, the knee locks will hold the paraplegic's weight if he cannot do so with his arms. When he is fully upright, preset latches at the knees and hips automatically engage, creating a rigid structure from base to torso-support. To sit, he disengages the hip and knee latches, and the capstan can be slipped gradually with the lock levers to allow controlled descent.

Thin-wall rectangular aluminum tubing forms the lateral struts of the upper module, representing a five-fold increase in lateral bending stiffness over the solid I-section of PACO II, and an 18 percent saving in weight. Also, the mechanisms which actuate the hip and knee locks are contained within the tubing, making the design cleaner and more reliable. Adjustment of the upper struts (knee-to-hip length) is accomplished by simply sawing the tubing to length and drilling four holes.

At this time assembly and distribution are being completed. The main disadvantage apparent in this concept at present is relatively poor cosmesis. It is our hope that this will be offset by the advantages, especially for active paraplegics. Evaluation of four PACO III units currently under construction should help clarify this question.

Goals for the Future

Stair-climbing is the most important remaining barrier whose elimination is asked by most paraplegics. Architects seem to delight in designing split-level homes, sunken living rooms, multi-step entrances in public buildings, and landscaping and house design which require entering halfway between two floor levels—making all of them inaccessible for the wheelchair-bound. Paraplegics object to such discrimination-by-design.

We believe that our crutch-less standing brace technology may become the first essential building block toward paraplegic stair climbing. That would eventually open the way to much better rehabilitation of paraplegics who are now excluded from that large

portion of the world accessible only over multiple closely-spaced steps. If a paraplegic could bridge the three-to-six-step barrier that now blocks his access to many public and private buildings, he could function usefully at many more locations.

Adequate rehabilitation has not been achieved as long as such large portions of the world remain off-limits to the independently moving paraplegic.

Engineering Applications in Orthotic and Prosthetic Treatment of Musculoskeletal Defects

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Three-Dimensional Gait Analyses

Since the last progress report, two additional normal subjects have been analyzed by means of our three-dimensional stroboscopic gait-analysis system. These studies have been helpful in improving the computer analysis as well as our EMG recording techniques. They have also been important in developing the computer software necessary to generate clinically useful graphic displays based on gait data. Because of the tremendous costs in time and energy involved in the stroboscopic studies, it has been resolved that maximum effort be directed towards the automation of the three-dimensional force analysis incorporating the Selspot System. Towards this end, the Selspot cameras have been mounted as they are to be used for monitoring motion, and careful tests have been performed to determine the precise capabilities of the system.

Two-dimensional kinematic studies have been carried out using each Selspot camera separately to record the motion of five light-emitting diodes (LED's) fastened to one leg and arm of a subject. The results were then displayed graphically as a stick-figure sequence. The system proves to be functional, but the errors at the limits of the cameras' fields of view are not acceptable (± 2.0 cm in the laboratory space). Optical synchronization also becomes marginal at the extremes, and may be entirely lost if the synchronization LED does not point directly enough at the camera. Other faults have also been discovered.

All these problems appear to be related to LED intensity. It is believed that minor changes in the LED driving circuits, and in-

corporation of more efficient LED's, will achieve the necessary improvements and may also eliminate the necessity for two light sources per anatomical target. Other circuit changes are anticipated which will cut power requirements for the LED's by 67 percent. This will greatly increase the possibility of battery-powered operation, which would eliminate the need for cables to the patient.

The software controlling the acquisition of Selspot data has been optimized to allow a sampling rate of 100 Hz, and has been modified since the last report to allow the analog-to-digital converter to acquire force-plate and EMG data in synchrony with Selspot operations. Three-dimensional kinematic analyses will be possible as soon as the new LED's have been incorporated.

Comparison of Five Orthoses, Including an Implanted Electronic Stimulator (NMA)

Although this study was initially targeted to include ten patients, no additional volunteers for the electrical stimulation implant (Neuromuscular Assist—NMA) were added to the study over this last reporting period. It has been decided, at this point, to analyze the information on the seven patients presently involved. Tests on these patients have been completed.

The Functional Electronic Peroneal Brace (FEPB) was found to be so difficult to use that completed tests including this brace were possible on only one patient. Difficulties included creeping of the electrodes away from the motor point, and skin irritation after prolonged use. The device was also very difficult for patients to manage at home.

The study on normal subjects mentioned in the previous report, in connection with the orthotic study, has been expanded to include 20 females and 26 males. The data based on normals have been more carefully studied since the last report, and some significant correlations between foot contact measurements and various independent variables (including body build) have been noted. A paper on this detailed study has been completed and will be submitted to Clinical Orthopaedics and Related Research.

As a consequence of these new findings the scoring system mentioned in the previous report has been modified. A paper on this aspect is being prepared and it is planned to submit it for publication during the next reporting period.

Functional Electrical Stimulation of Paralysis of Musculature of the Hip

The design of the microprocessor-based stimulation system to be

used in this study was completed during the last half of 1976. Fabrication has been initiated.

Some problems with movement and breakage of the implanted electrodes have been experienced in the experiments to determine the functional contributions of the various hip muscles. Experiments to determine the exact cause and to find solutions to these problems are under way at Case Western Reserve University. Some larger-diameter coil wire electrodes will be tested here in the near future. It is believed that these will be less vulnerable to breakage.

Patient Evaluation of a Functional Electrical Stimulation Hand Orthosis

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The purpose of this project is to evaluate clinically the performance of an orthotic system which provides spinal-cord-injury patients with controlled hand motion, and to investigate the feasibility of deploying this system to a larger group of patients in more extensive clinical testing. The system employs electrical stimulation of the finger flexor and extensor muscles of C5 quadriplegic patients to provide controlled prehension and release, respectively. Evaluation of the orthosis will include testing of the system for performance parameters as well as evaluation of the clinical acceptability of the device to the patient.

The system under development (based on a prototype system developed in the Applied Neural Control Laboratory at Case Western Reserve University) operates as follows:

1. The position of the head or shoulder is transduced and used to control the stimulus delivered to the appropriate finger flexor or extensor muscles;
2. Chronically indwelling percutaneous coil wire electrodes are used to apply the stimulus;
3. Automatic control has been added to enable the patient to choose and reset his zero reference position, and hold the stimulus output regardless of his proportional signal. These functions are controlled by a processed, two-level myoelectric signal.

The prototype unit is inconvenient for the patient to use because it is large and heavy, and therefore restricted to non-portable use. Furthermore, interconnection to the patient is awkward and time consuming. These limitations have made the units unacceptable to

the patient for routine daily use. Miniaturization of the device would promote its acceptance.

Two phases are involved in fulfilling the goals of this research project. The first phase is the design and fabrication of the miniature stimulation hardware and controls in a form suitable for use by the quadriplegic patient and his attendant. The second phase involves the evaluation and deployment of these systems to the patients. The primary involvement to date has been in fabrication of an appropriate device.

The system under development operates conceptually the same as the prototype system, except that provision has been made for the alternate (myoelectric) control scheme. This feature allows selection of one of two control schemes, depending upon which is more appropriate to the individual patient.

The primary focus has been on miniaturization. In order to achieve the small size, convenient use, and reliable performance required by the patient systems, major hardware redesign of the CWRU system has been necessary. Specifically, the circuitry has been redesigned to utilize a minimum number of components consistent with reliable operation, and with minimum current consumption requiring the fewest possible batteries. Throughout the design, a modular approach has been utilized; this approach will allow individual blocks to be translated into the design of future devices for similar applications. Design of modular blocks for this system has been completed and all except one has been constructed and tested.

The test modules have been combined into an operational laboratory stimulator. This unit will serve two purposes. First, it will be used by patients in the laboratory prior to miniaturization to insure proper operation of the patient version. Second, since the large device exactly replicates the operation and circuitry of the small units, it will be used to determine control and stimulus parameters which will vary from one patient to another—these can then be fixed in each individual's personal stimulator. This allows further reduction in size by eliminating all internal potentiometers.

Throughout critical stages of design, patients who will be candidates for this system have been involved in evaluating various aspects. In particular, experiments were performed to examine the problem of interference of the stimulus artifact on the myoelectric signal (MES). The results demonstrated that gating the MES amplifier off during the presence of the stimulus artifact eliminated this problem.

In the next period, proper operation of the laboratory unit will be ascertained and the design implemented in the miniature patient

devices. The goal is to fabricate units which have external dimensions of roughly 4 × 6 × 2 in. The circuitry will be produced on printed circuit boards using miniature components and high-density techniques. To provide easy use by the patient, the device will require only a single connector to activate the system, and mercury batteries will be used to eliminate the need for recharging; anticipated battery life is approximately 2 months with expected usage.

At present, three patients who are candidates for use of this system are working with these investigators.

Ultralight Below-Knee Prosthesis

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The contract with the Veterans Administration for development of a practical ultralight below-knee prosthesis became effective October 6, 1976.

The original concept, which has not changed, was to provide a crustacean-type below-knee prosthesis of molded sheet polypropylene, that would consist of only three parts—the socket, the shank-foot section, and a sole-and-heel section (Fig. 18). Any or all functions provided by the variations of the conventional PTB prostheses can be obtained, the only change being reduction in weight and any consequent shift in the center of gravity.

Experience before and since October 6, 1976, has shown that the properties of sheet polypropylene are quite satisfactory for use of this material in the fabrication of sockets, shanks, and feet for below-knee prostheses (Fig. 19, 20, 21). Workmanship, of course, plays a considerable role in the strength of the assembly. Northwestern University has conducted some tests to destruction and found that prostheses made of polypropylene at NU according to our instructions were quite satisfactory.

Most of the time has been spent on development of a practical method for fabrication of the foot section. Two fairly comparable methods have evolved. In one, a temporary foot is made by forming polypropylene over a SACH foot to form a hollow foot, which is used during dynamic alignment and (later) as a mold for the positive foam model over which the definitive foot-and-shank section is molded. The alternative method uses an external-keel type of SACH foot during alignment, and the keel as part of the positive model.

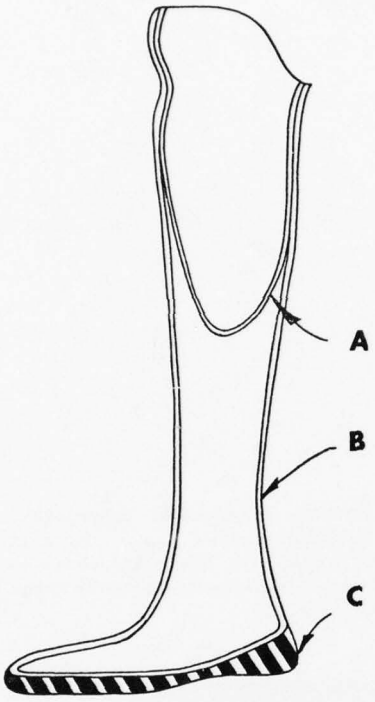

FIGURE 18.—Crustacean-type below-knee prosthesis: A. molded polypropylene socket; B. molded polypropylene shank and foot; and C. sole and heel cushion.

Both methods have advantages and disadvantages when compared with each other, and both will be presented in a manual which is being prepared for submission to the Research Center for Prosthetics.

It is anticipated that one manufacturer or more will make available either mass-produced (probably blow-molded) polypropylene feet, or specially sized external keels, to reduce shop time.

Because of the tremendous reduction in weight (approximately 60 percent) the problem of suspension is reduced, and it has been the custom here to provide supracondylar brims that require no auxiliary suspension devices such as belts, cuffs, or wedges. Polypropylene sockets are accepted quite well by the patients, and are in fact preferred by most because of the "feel."

A manual will be completed by March 15, 1977. Though not specified in the contract, a report on patient use and reaction is being compiled.

A field study or large clinical evaluation appears to be in order.

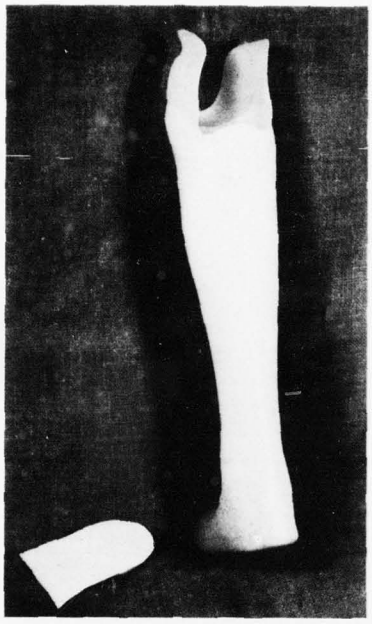

FIGURE 19.—Ultralight polypropylene below-knee prosthesis before attachment of heel cushion. This patient prefers no sole cushion, but wears shoes with sponge rubber soles.

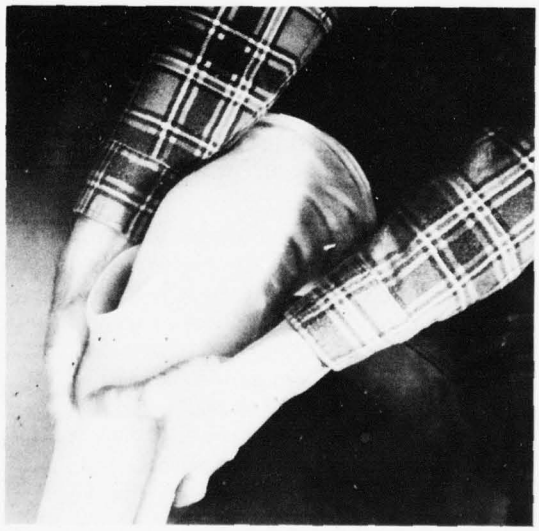

FIGURE 20.—*Patient donning the ultralight below-knee* prosthesis developed at Temple University.

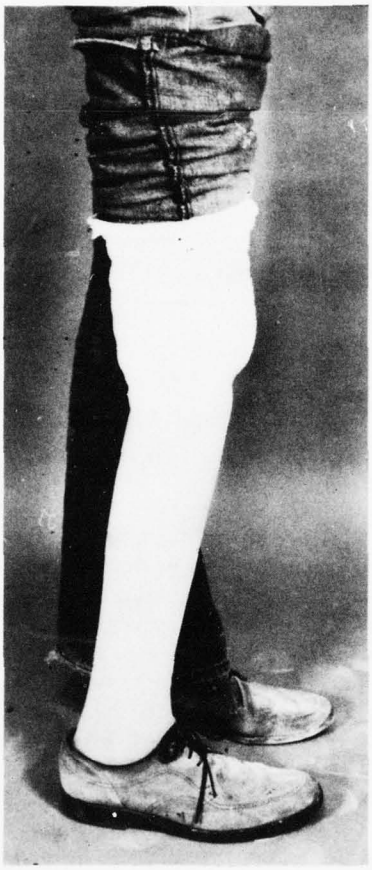

FIGURE 21.—Patient wearing an ultralight polypropylene below-knee prosthesis.

Orthopedic Implant Device Retrieval and Analysis
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It is the purpose of this investigation to retrieve all orthopaedic devices which are removed during the normal and routine medical care of the patient and correlate the medical histories, surgical findings, histological evaluations and radiographic reviews with the characteristics of the materials from which the implants are manufactured. Implants are retrieved on both a restrospective and prospective basis. All patients receiving orthopaedic implants are followed from the time of insertion.

Medical data and metallurgical data forms are being used which are essentially identical to the ASTM F-4 draft document entitled "Standard Recommended Practice for the Retrieval and Analysis of Metallic Orthopaedic Implants." There are currently 15 patients in the study; 8 prospective and 7 retrospective. The devices retrieved cover the standard armamentarium of the orthopaedist.

No correlations of data have as yet been attempted.

Evaluation of Electrical Techniques for Stimulation of Hard Tissue Growth

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Background

The main thrust of this program has been to determine the factors that stimulate and control growth and healing in the musculoskeletal system, so that clinical applications may be made.

From the viewpoint of basic biological knowledge, several factors were clearly evident when we began our studies in 1958. First, the healing of an injury is a controlled process; i.e., in the normal condition, cellular activity is "turned on" in response to the injury, proceeds until healing is complete, and is then turned off. From this point of view it is a classic example of a feedback control system. Secondly, when the entire spectrum of the animal kingdom is looked at, it becomes apparent that the healing processes of more primitive animals are far more competent than those of the human.

Of particular interest to us is the healing process of regeneration in which a missing portion of the body is regrown into a normal complex structure. The salamander, for example, is capable of regenerating a limb in a few weeks. The structure of the salamander limb is as anatomically complex as the corresponding human limb. Why then is it that we cannot regrow our limbs? The question: What are the factors that stimulate and control regeneration of the salamander limb? would appear to be clinically pertinent. In the human, the only truly regenerative growth that we possess is the healing of fractures: therefore, knowledge of these factors would at least be useful in the treatment of non-unions of fractures in the human. Furthermore, such knowledge may well be put to clinical use in stimulating regenerative growth that we as humans no longer have. Such growth control would be applied not only to the re-

growth of limbs, but more immediately (and more pertinently) to such structures as skeletal muscle, cardiac muscle, peripheral nerve and spinal cord, joint cartilage and total joints in general.

We began our studies in 1958 with an evaluation of a factor previously thought to be unrelated to any control function—the electrical current of injury. This is revealed by an electrical potential which can be measured at any site of injury in any living organism. We found that the current of injury persists throughout the entire time of healing, and that it follows an entirely different sequence of changes in injuries healing by regenerative growth than it does in similar injuries in other, but closely related, animals not capable of regenerative growth (1). The pattern is so striking that it was concluded that the local electrical factors at the injury site represented only a signal resulting from the operation of a control system that permeated the entire organism.

Intensive study was devoted to this issue, and it was determined that these electrical potentials are related to the central and peripheral nervous system where they represent the activity of another mechanism more primitive (than the well known action potential) for the transmission of data. The present concept is that this analog-type data transmission and control system antedates the action potential system, and that it is responsible for a number of primitive functions in addition to growth control. Such additional functions defined so far include; (i) pain sensation, (ii) general level of excitability of the action potential system, and (iii) control over biological cycles. Most recently we have acquired data indicating that this system may be residing in the perineural cells of the CNS, the glia cells centrally, and the Schwann cells peripherally. While numerous papers have been published in this area of neuroelectronics, two recent publications summarize and present the data within the systems concept (2,3).

From a clinical point of view, we were primarily interested in the output of the system that appeared to have growth stimulating and growth controlling properties. Since growth is perforce the result of cellular activity, and since regenerative growth requires not only mitosis, but also a dedifferentiation (a return to a primitive cell type) we directed a study at the results of exposure of cells to various levels of direct current. Our test system was the nucleated erythrocyte, and we found that dedifferentiation did indeed occur, but only in a narrow range of current and voltage of extremely low values (4,5). We were then able to proceed to determine, in detail, the control system that regulates regenerative growth in general and fracture healing specifically (6).

Obviously, the primary question is: With this knowledge, is it

possible to stimulate some measure of regenerative growth in mammals?

In our experiments in 1972, we amputated the foreleg of laboratory rats between the shoulder and elbow and implanted small electrical units designed to produce the appropriate level of current. We obtained gratifying regrowths, occasionally as far as regeneration of the entire distal humerus complete with an elbow joint of normal histological appearance (7,8). In similar experiments which are unpublished, we were able to stimulate considerable regrowth of the proximal humerus, an important point since in this instance, growth is proceeding proximalward. Such "upstream growth" does not normally occur even in animals capable of regeneration.

The first clinical application of this knowledge has been in the area of un-united fractures. Over the past 3 years we have treated a variety of cases with various electrical techniques. We have found that growth can be stimulated solely by appropriate electrical currents and voltages (which must be in the biologically significant range). A recent publication presents all the technical details (9).

Several points must be emphasized at this juncture. First, while all electrical parameters are designed to be well below the level of harmful effects, they are further designed to duplicate, in so far as is presently possible, the values that would have been produced at the time of the original fracture by the patient's own electrical control system. Thus, we are employing a simulation of a natural biological process and not some modality that is foreign to the body.

Secondly, such simulation can only approximate a natural biological process when the electrical parameters are injected by metallic electrodes. The electrochemical events that occur in the immediate vicinity of a metallic electrode passing current are poorly understood for simple systems, and are completely unknown for biological systems. A complete systematic study of these processes is urgently required before the full potential of this growth control process can be clinically realized. We are presently beginning such a study. From an orthopedic point of view, the possible clinical applications have been indicated in a number of publications (10, 11, 12). Obviously other clinical applications can be entertained, ranging from effective pain control to stimulation of bone growth into suitable metallic devices to provide anchorage points for external prostheses.

Most recently we have investigated the possible application of our techniques to situations requiring growth retardation rather than stimulation. Since, biologically, all active growth processes are

characterized by high electrical negativity, we had always employed metallic electrodes (generally silver) driven negatively (cathode) in both animal and human studies. The obvious question then was, would positive potentials retard growth? We found that metallic electrodes, when used as the anode, are very active electrochemically and in general, exhibit a tendency to give off, and drive into the local tissues, metallic cations (a silver electrode will inject silver ions, a platinum electrode, platinum ions, etc.).

Thus, at this time, we have been unable to generate a pure anodal environment without the accompanying electrochemical changes. However, this tendency to emit positive metallic ions from the anode has itself proven to be of very great clinical interest. For example, silver has been long recognized as a potent antibacterial with little, if any, harm to the mammalian cell system. The problem in its clinical use has been that silver compounds either dissociate very little and are ineffective, or they dissociate readily and are toxic. Metallic silver foil is still used frequently by European surgeons as a primary wound dressing; however, the emission of silver ions from it is negligible. We found that silver electrodes, when driven positive, will readily emit silver ions which will migrate along the lines of voltage gradient, penetrating tissues for approximately 1 cm. These are unaccompanied by any new anion and are non-toxic to mammalian cells.

Their anti-bacterial spectrum appears to be complete and we have found no type of bacteria that cannot be killed with this modality.

We have tested this concept clinically in 12 cases of osteomyelitis, with excellent results. It now appears that for local infections, we have an extremely effective treatment modality which can effectively suppress all varieties of bacteria and a number of fungi in tissues with poor blood circulation without damaging the host cells or tissues. A full report is in preparation.

This technique may be used to drive other metallic cations into tissues, although little is known about the resultant effects. We have experimentally applied the concept to one other system—the rheumatoid arthritic synovium. Here it has been known that gold, systemically administered, is effective in suppressing the synovial cell overgrowth. The problem was that the majority of patients exhibited no effect because the gold did not penetrate the affected joint spaces. In animals with experimental arthritis, we found we could effectively suppress the synovial cell overgrowth by inserting a gold wire into the joint cavity and driving it positive, with a current and potential below electrolysis levels, with one treatment or 30 minutes duration. Obviously the gold ions are injected directly

into the desired site and there is no total body burden of gold with its known toxic effects. It would appear feasible to consider further exploration along these lines in rheumatoid arthritis and other conditions, as long as the target cell or tissue to be suppressed was sufficiently different from the normal cells or tissues.

Present Investigations

The laboratory is presently involved in a systematic study of various techniques for the injection of electrical forces into tissues, particularly bone, in an attempt to define the optimal safest method for stimulation of bone growth. We are also involved in a study of the biological effects of electrical fields of various types, to search for beneficial or harmful effects. We also hope to begin a systematic study of a variety of metallic electrode systems in biological tissues to elucidate the electrochemical changes that occur, and to search hopefully for other useful biological effects.

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SENSORY AIDS

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Research on Audible Outputs of Reading Machines for the Blind

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Introduction

Haskins Laboratories has for some years been developing procedures for the synthesis of speech by rule for use in a reading machine for the blind, exploiting a large body of basic research on speech cues carried out at the Laboratories since 1950 as well as similar research by others. At present, two systems for synthesis-by-rule are available, and progress was made with both during the second half of 1976. In addition, further investigations in acoustic phonetics have been undertaken in support of the synthesis work.

Development of Rules with the FOVE Program

FOVE is the synthesis-by-rule program for the DDP-224 computer, which calculates parameter values to drive the OVE III hardware synthesizer. During the first half of 1976 this program was extensively revised; since then, improvements have been made to the set of rules for American English used in conjunction with the program. A better set of stop consonant bursts has been achieved by the use of a 5 ms rather than a 10 ms sampling interval, and increased naturalness of vowels by increasing the bandwidth of the second formant. A round of subjective tests, using the same word-lists and sentences as were used in earlier tests, has been conducted, but results are not yet available.

Research Synthesis by Rule

A prototype synthesis-by-rule program, called SYLSYN, has been written in FORTRAN for the PDP 11/45. The program is organized in terms of phonetic syllables, with a view to providing a more direct representation of coarticulatory effects on spectral and temporal aspects of speech than is possible with a program organized (as is FOVE) in terms of phonetic segments. The input to the program is a transcription in syllable features. The rules are stated in a FORTRAN subroutine called RULES that can be revised independently of the main program; these rules relate the feature transcription to a specification, as a function of time, of each of the various articulatory influences that shape the syllable. These influence functions, in conjunction with target values specified in the rules, are used to determine the parameter values for a software synthesizer; this synthesizer produces a sequence of digital values which is converted to an audio signal. By editing the RULES subroutine, the user of the program can readily modify not only the rules for synthesis but also various characteristics of the synthesizer itself. At present SYLSYN can synthesize only vowels, glides, and diphthongs, and the synthesizer has only a vowel branch. Programing continues with a view to enabling both SYLSYN and the synthesis routine to deal with all classes of speech sounds.

Temporal Variation and Speech Synthesis

In order to increase our knowledge of the temporal patterns of natural speech, so as to be able to produce more natural synthetic speech, a series of production experiments has been undertaken to study the timing of events within a syllable. In a typical experiment, a speaker is asked to repeat, 30 times each, two sentences that differ with respect to just one syllable feature; for example, "She was seen on pay street by her mother" vs. "She was seen on play street by her mother." Such data are used to assess the effect on the temporal pattern of the syllable of particular articulations (such as the /l/ in the example) initially and finally, alone and in clusters.

Results of experiments so far suggest that, for any one speaker, the duration of the acoustic segment corresponding to a given syllable-initial articulation varies according to cluster context, while the increment to the syllable duration that can be attributed to the articulation is more nearly constant. In the case of final articulations, however, this is clearly not the case: the increment to the syllable duration attributable to the final cluster of *pained,* for example, is much greater than the sum of the increments attributable to the final consonants of *paid* and *pain.*

Segmental Cues

As part of the effort to achieve better rules, the transitional cues for perception of voiced stops, determined with the Pattern Playback in the early 50's, are being re-examined, using OVE III. A number of variants of the vowel [a], representing different vocal-tract sizes and different degrees of backness and openness, have been synthesized. For each of these variants, the range of transitions appropriate for [b], [d], and [g] have been informally determined. It is planned to conduct formal identification tests for both vowels and stops.

Research and Development in the Field of Reading Machines for the Blind

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The report on activities in the latter half of 1976 is incorporated in an article, "Research and Development in the Field of Reading Machines for the Blind," appearing elsewhere in this issue of the Bulletin.

Clinical Study of Mobility Aids for the Blind

Central Rehabilitation Section for Visually Impaired and Blinded Veterans
VA Hospital, Hines, Illinois 60141
John D. Malamazian, Leicester W. Farmer, and James J. Whitehead

During this reporting period, two veterans were admitted for training with the electronic aids (ETA's). One veteran, a dog guide user, was trained with the Sonicguide and the other, who was admitted in November, is being trained with the C5 Laser Cane and will complete his training during the next reporting period.

In July, Mr. Leicester W. Farmer journeyed to Nashville, Tennessee, to give a lecture and demonstration on ETA's at a workshop on "Aging and Blindness" at the Howard Johnson Motor Lodge. The workshop was sponsored by Services for the Blind, the American Foundation for the Blind, and the Tennessee Commission on Aging.

Mr. Farmer was invited to a Training Seminar for Visual Impairment Services Teams August 23-25, 1976, to be available as a

resource person on ETA's. The Seminar was held at the Ramada Inn South, in St. Louis, Missouri.

Mr. Norman Pressey, International Marketing Manager for Wormald International Sensory Aids Limited (WISA) of Christchurch, New Zealand, visited Hines in September. WISA manufactures the Sonicguide, which is distributed in the United States by Telesensory Systems, Inc. Mr. Pressey discussed training procedures, deployment considerations, development of training manuals and tapes, and communications among Orientation and Mobility (O/M) Specialists, technologists, and device manufacturers, with Mr. Farmer. He announced that the Mowat Sonar Sensor (a handheld sensory aid) which was developed by Mr. Geoff Mowat of Auckland, New Zealand, will be manufactured by WISA and marketed in 1977. Mr. Pressey showed "An Introduction to the Sonicguide," a 10-minute 16mm color film which introduces the Sonicguide, presents a brief review of the potential of the device, and shows adults using Sonicguides in various employment and travel situations.

In September, Mr. Walter Thornton from the United Kingdom visited Hines and discussed training procedures, device deployment and usage, and ETA accessory telemetry equipment in Great Britain.

Mr. Farmer spoke on ETA's and sensory systems to a class of seniors at West Leyden High School in Northlake, Illinois, and in December gave a speech and demonstrated the ETA's to the Lions Club of Evanston, Illinois.

Hines ETA Program Reviewed

A review of the Hines ETA Program, from 1971 when the first veterans were trained, has been completed during this reporting period. Three of the ETA's which showed early promise have been field-tested and are used in the VA programs (the Lindsay Russell Pathsounder, the Laser Cane, and the Sonicguide). A summary of the findings relative to training and device deployment, use, retention, and return are reported as follows:

Lindsay Russell Pathsounder

Some 19 veterans have been trained to use the Lindsay Russell Pathsounder; two of them completed the regularly prescribed ETA Program both indoors and outdoors in the various travel settings.

Five of the veterans had head injuries. Five were ambulatory although one of these had to use a wheelchair some of the time. Twelve veterans were either confined to wheelchairs (or used crutches or a wheelchair) due to lower-limb amputations, paralysis, or hemiplegia. All trainees participated in the ETA Program while

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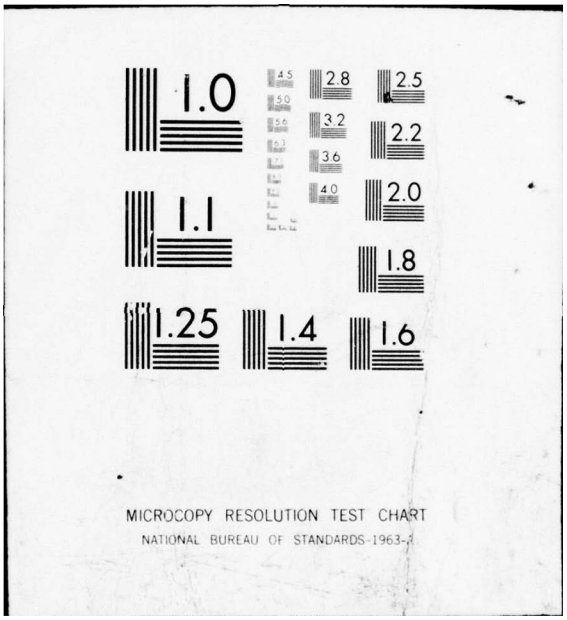
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undergoing training in the regular rehabilitation program.

No Pathsounders were issued to any of the trainees.

Bionic Instruments, Inc., Laser Cane

A total of 14 veterans have been admitted to the Hines Blind Rehabilitation Center for training with the Laser Cane. One veteran could not participate in the ETA Program because his cane technique and basic O/M skills were too poor. One veteran received training with the Laser Cane for 6 weeks but still was unable to learn to use the aid adequately.

Of 12 veterans who received training with the Laser Cane, 9 currently have Laser Canes; 8 of these continue to use the cane as their primary travel tool while 1 very seldom uses his cane. Of the three veterans who returned the canes, one did so because he lost the hearing in one of his ears and now uses a dog guide. Another veteran returned his Laser Cane and received training with the Sonicguide, and the third veteran died a few months after returning home with his cane: his wife returned it to the Hines Blind Section.

Since November 1974, seven veterans have been trained to use the Laser Cane.

WISA Sonicguide MK II

Some 29 veterans have been admitted to the Hines Blind Rehabilitation Center for training with the BSA/Sonicguide. One veteran could not participate in the ETA Program because of poor cane technique and travel skills, one veteran completed 4 weeks of the training program before terminating his participation in the course, and a third veteran had only 9 days of exposure to the ETA's before deciding that his dog guide was all he needed to achieve satisfactory, productive travel.

Twenty-six veterans have been trained and issued BSA/Sonicguides: of the 26, 9 have returned their aids while 17 have retained the devices. Some six of the veterans who have Sonicguides are regular users (use the aids daily), six more are moderate users (at least three times per week), four are occasional users (1-2 times per week) and one very seldom uses his aid.

Since November 1974, 10 veterans have been admitted for training with the Sonicguide and of this number, 5 trainees used dog guides. It is interesting to note that of the six regular Sonicguide users, four are dog guide users.

Of the first 16 veterans trained with the BSA/Sonicguide (starting in 1971), 8 have returned their devices. Five veterans returned the aids in less than a year after completing the ETA course and

four users kept the devices from 3 to 4½ years after returning home with the travel aids.

Table 4 shows the training, deployment, returned aids, retained devices, and use of the three ETA's.

TABLE 4.—*Hines ETA Program Reviewed*

	Pathsounder	Laser Cane	BSA/Sonicguide
Veterans trained	19[a]	12	26
Devices issued	0	12	26
Devices returned	0	3	9
Devices retained	0	9	17
Regular users	0	8	6
Moderate users	0	0	6
Occasional users	0	0	4
Seldom use device	0	1	1
Percentage returned	0	25%	35%
Percentage retained	0	75%	65%

[a]Two veterans who were undergoing O/M training in the regular program and without additional handicaps were trained to use the Pathsounder in all areas of the live environment outdoors as well as indoors.

Clinical Trials of Reading Machines for the Blind

Central Rehabilitation Section for Visually Impaired and Blinded Veterans
VA Hospital, Hines, Illinois 60141
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This project is concerned with the clinical application of reading machines and other communication aids for the blind. The major activities and programs of this reporting period are described.

1. Mr. Harvey Lauer (research staff) completed writing the proposal to evaluate the Kurzweil Reading Machine. This instrument has optical character recognition logic, automatic scanning and synthetic speech output. The research proposal will be modified for other OCR machines for the blind as they emerge from laboratories. The VA's OCR machine is called the Cognodictor. Both it and the Kurzweil Machine are scheduled to appear in prototype form in several months.

2. Most of the assessment and instruction of veteran candidates for the currently-available reading machines was done by Mr. Leonard Mowinski of the Blind Center Staff. Mr. Lauer and Mr. Mowinski described and demonstrated communication aids at a workshop for

Optacon teachers given at Northern Illinois University, DeKalb, Illinois. These same activities are routinely done for personnel on detail at the Blind Center.

3. Some of the products of the Stereotoner Project conducted for the VA by the American Institutes for Research (AIR) were disseminated. There are pretraining tapes, a test for assessing candidates, manuals, and a report of the project. Mr. Lauer has updated for publication his article about reading aids for the blind.

4. Mr. Lauer and Mr. Leicester W. Farmer (research staff) wrote and updated the research proposal for the ongoing evaluation of reading and mobility aids at Hines. It was submitted for review under the auspices of Research Center for Prosthetics.

5. Dr. William De l'Aune, researcher at the VA Eastern Blind Rehabilitation Center, spent 3 days at Hines. He conferred with Mr. Lauer and other staff members regarding statistical analysis in the Kurzweil Project. All of our research interests were discussed in this valuable program of cooperation between our respective Centers.

6. Mr. Lauer made two of three needed instructional tapes on the use of current speech compressors and provided copies to the other Centers and the manufacturers.

7. Studies were made of the availability, applications, and operating characteristics of instruments in the three following areas: a. Audible-output light probes (light sensors), b. Speech amplifiers and transducers for laryngectomy patients, and c. Calculators with visual displays (usable by low vision patients).

Clinical Application Study of Reading and Mobility Aids for the Blind

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The report on activities in the latter half of 1976 is incorporated in an article, "A Preliminary Followup Study of Electronic Travel Aid Users," appearing elsewhere in this issue of the Bulletin.

The Development of Improved Techniques for the Analysis of Hearing-Aid Performance

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Developmental Measurement Techniques

A major effort in our laboratory has been to develop techniques whereby nonlinear (intermodulation and harmonic) distortion and transient distortion in hearing aids can be more adequately quantified. Currently, no standard methods exist for measurement of these electroacoustic features. The ultimate purpose of this developmental work is to determine the effects of these types of distortion on speech intelligibility and speech quality.

In the area of nonlinear distortion, pure tone test signals have been de-emphasized; these are being replaced by more complex, and thus more realistic, signals. Tests using selectively shaped random noise and synthetic vowels have been studied. These efforts have benefitted substantially from a loan of synthetic formant generators by Gallaudet College for the Deaf. Future utilization of the synthesizer is expected to result in the development of methods for evaluating the effect of compression ratio on the perception of second-formant transitions.

Findings from work completed thus far reveal the following:

1. The rank order of hearing aids on the basis of distortion is significantly dependent on the specific frequencies chosen as a test signal;
2. The amount of masking of a tone introduced in a gap surrounded by random noise is directly related to the amount of nonlinear distortion of the system under test; and
3. The spectral shape of synthetic vowels undergoes significant "warping" when transduced by some hearing aids. This is due not only to frequency response characteristics but particularly to nonlinear distortion.

In our study of transient distortion, initial efforts have been directed at producing an acoustically pure signal, free of the transient distortion frequently exhibited by the loudspeaker source when pulsed sinusoids are generated acoustically. The development of a phased-array technique, wherein the relative phase of signals fed to two loudspeakers is digitally manipulated, appears to satisfy the basic requirements for generation of tone-burst signals for use in transient-distortion measurements. Such a technique has been developed in parallel with our work in attack-release time

measurements in compression aids; therefore, the availability of the technique also represents an advance in reaching the goal of greater accuracy in attack-release time measurements.

To aid in our study of nonlinear and transient distortion, and their effects on quality and intelligibility of speech, development of digital microprocessor circuits has been begun by Daniel Graupe, Ph. D., of Colorado State University. Use of this circuitry will allow us to vary these parameters systematically without concern for the contaminating influences of numerous other electroacoustic characteristics.

Hearing Aid Processing

Since much of our work involves the use of hearing-aid-processed speech, a portion of our efforts has been aimed toward evaluating any existing differences between the frequency response of a hearing aid at the eardrum in actual-use conditions, and that when speech is processed via either a 2cc coupler or Zwislocki coupler and delivered to the listener through an earphone. The completed results indicate that the two circumstances yield different responses, primarily in the lower frequencies, but to some degree in the higher frequencies as well. We are, therefore, employing appropriate correction factors in most of our work that involves hearing aid processing. These corrections are particularly warranted in studies where clinical indices of performance are related to real-life performance with the actual instruments.

Study of Aided-Speech Quality Judgments

Work was continued on the determination of the reliability of hearing aid quality judgments. Preliminary findings reveal that normal listeners rank hearing aids similarly, regardless of whether the stimulus material consists of a male voice, female voice, or music. Furthermore, the quality preferences appear to be clinically reliable. Data on sensorineural listeners are presently being collected for the purpose of assessing whether hearing-impaired listeners rank hearing aids in a similar fashion, as do normal-hearing individuals.

Workshop Activity

An initial effort has been taken toward achieving our long-term goal of enhancing the ability of VA audiologists to provide rehabilitation for the hearing-impaired. On December 1-2, 1976, our laboratory staff conducted a workshop in Little Rock, Arkansas, cooperatively sponsored by the VA Hospital (Little Rock), the University of Arkansas at Little Rock, and the University of Arkansas for Medical Sciences. The topic was, "Elements of Hear-

ing Aid Performance and Aural Rehabilitation." Participants were 40 audiologists, most of whom were from the VA setting, and active in direct patient care involving hearing aid evaluations and/or rehabilitation. Long-range benefits of the workshop to the participants are to be quantified at a future date, but initial reactions of those in attendance encouraged the belief that a workshop format provides the opportunity for transmission of concepts that can be productively employed in enhancing clinical skills. It is our intention, therefore, to continue our involvement in this type of activity in the future.

Insertion Gain Measurements on KEMAR

A comparison was made between the acoustic gain of hearing aids obtained on KEMAR utilizing both the insertion gain and substitution measurement methods.

With the insertion gain method, the microphone attached to the Zwislocki coupler in KEMAR'S ear (the eardrum microphone) was made the regulating (control) microphone, by activating the compression circuit. The output of the oscillator, controlled by the compression circuit to produce 60 dB SPL throughout the frequency range from 150 to 10,000 Hz, was recorded on magnetic tape by the Scully model 280 tape recorder.

The coupler microphone was then converted to the measuring microphone, and the tape-recorded signal was played back through the loudspeaker to KEMAR and picked up by the Zwislocki coupler (eardrum) microphone. A flat frequency-tracing on the graphic level recorder indicated that the sound pressure at the eardrum microphone (designated the test point) was the same as when the compression circuit was used. In this manner, the effects of loudspeaker response, KEMAR effects (head diffraction and ear canal), and field effects were compensated for. The tape-recorded signal, the voltage required to produce constant SPL across frequencies at the eardrum microphone, was then used as the test signal for measurement of hearing aids.

(For practical reasons, we found it necessary to record a 1000 Hz tone prior to the sweep frequency response. This tone was used to adjust the level of the hearing aid response to the recording paper.)

To measure hearing aid gain using the substitution method, a 1/2-in. condenser microphone was connected to a compression circuit. With KEMAR out of the chamber, the microphone was placed at the test point, a position which was the same height as KEMAR's ear canal at a distance of 1 m from the loudspeaker. The oscillator output, controlled by the compression circuit to produce 60 dB SPL throughout the frequency range from 150 to 10,000 Hz, was

recorded on magnetic tape by the Scully model 280 tape recorder. The tape-recorded signal was played back through the loudspeaker to the 1/2-in. condenser microphone and the resulting response, as indicated by a flat frequency tracing on the graphic level recorder, represented a constant input sound pressure level as a function of frequency at the test point. The use of this technique compensated for the presence of any loudspeaker and room reflection effects. KEMAR (with previously described coupler assembly) was then placed in the anechoic chamber at the test point. This tape-recorded signal was used as the test stimulus for measurement of hearing aids using the substitution method.

It is apparent that the differences between the two methods are observed primarily in the frequency range above 1500 Hz with the substitution method response generally showing more gain. However, the amount of difference between results with the two methods is not constant across hearing aids. The differences among hearing aids might be explained by the differential effects on the response of hearing aid case diffraction, hearing aid microphone location, and coupling of the hearing aid to KEMAR.

The differences in the effect of the two methods on measurements of hearing aid frequency response are clearly explained by the procedures inherent in preparation of the test signal.

The question then becomes, which method should be used for measurement of aids on KEMAR? It is our feeling that both methods are valuable.

The orthotelephonic response, recently named the "insertion gain response" of the hearing aid, represents the differential pressure at the eardrum with a hearing aid in place less the pressure without a hearing aid. The pressure without a hearing aid is that of the normal ear (as represented by KEMAR's response) and it is removed from the hearing aid frequency response. The result is the signal as seen by the hearing aid and measured at the eardrum microphone. The task remains to devise an audiological procedure that relates hearing sensitivity to the orthotelephonic response of a hearing aid. The work of Cole (1975) represents an attempt to relate the difference between aided and unaided pure tone thresholds to the orthotelephonic response of the hearing aid.

The response obtained using the substitution method is the difference between pressure at a test point and pressure at the eardrum with a hearing aid in place. The resulting response represents hearing aid performance on a median person, KEMAR. At this moment, this technique seems to have a great deal of face validity, but does not relate to present routine clinical measures.

The ultimate procedure, of course, should be the one which re-

lates to the hearing-impaired person's performance with a hearing aid. It is our belief that behavioral measures will be necessary to validate the question as to which method is superior. We have this task before us.

Clinical Application Study of Reading and Mobility Aids for the Blind

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During this reporting period most of the energies of the blind center research staff were directed into the physical movement of staff and equipment to new quarters. This relocation, dictated by the expansion of the blind center itself, is now completed and research activities are rapidly regaining lost momentum. The new research space is more satisfactory than that previously used, as it allows all research operations to take place in one area.

A paper, "Parameters of Success in the Use of Fresnel Prisms," by P. Gadbaw, W. Finn, M. Dolan, and W. De l'Aune, was published in the December 1976 issue of Optical Journal and Review of Optometry. It summarized the center's research to date on the use of prisms as a mobility tool for individuals with restricted visual fields. The importance of visual acuity, motivation, and psychological "health" in predicting success was emphasized.

Ms. Gadbaw took part in a panel discussion of the subject "Teaching Low Vision Aids in a Clinical versus a Home Environment" at the New England American Association of Workers for the Blind Chapter Meeting in Portland, Maine, in October 1976. Her presentation made use of the preliminary results of the ongoing survey of blinded veterans issued low vision aids from the Eastern Blind Rehabilitation Center.

The computerized accumulation of demographic, psychological, and medical data on veterans involved with the blind center's programs has been expanded to include information on all clients seen at the center prior to December 31, 1976. We now have demographic information on 559 blinded veterans, Minnesota Multiphasic Personality Inventory scores for 244, California Psychological Inventory scores for 228, and Wechsler Adult Intelligence Scale IQ scores for 331. These data, in conjunction with consumer

oriented questionnaires, are used for determining the adequacy of training for different subgroups of the blinded veteran population. The data base also provides ready access to many user variables when a relationship between a sensory aid's function and the characteristics of a successful user population are to be assessed. Preliminary discussion concerning expansion of this system to include all of the blind rehabilitation centers has taken place between Dr. De l'Aune and representatives of the other BRC's.

An audiometer was obtained through the CRIP program and will be used in conjunction with the sound-attenuating test booth previously acquired through the same program. It is hoped that on-site testing of auditory characteristics of blinded veterans will provide the researchers with a better understanding of the processes involved with mobility tasks undertaken with and without sensory aids. The system will also be used for implementation of the experimental auditory training regimes previously developed by the research staff. It is also hoped that additional information about the effects of hearing aid use on the mobility performance of blinded veterans will be gained.

Preliminary Evaluations

Evaluation of Lucheck Lighted Cane.—A preliminary evaluation of the Lucheck Lighted Cane prototype was conducted by the center's mobility staff in conjunction with the research department. A cane was forwarded to the CBRC's research department for comment.

Although the cane was seen to have some potential merit in terms of safety in night travel, very little enthusiasm for the concept was expressed by either the blind clients or the sighted O&M instructors. It was felt that the device should be made available to those who wish such an aid, and it will be shown to all clients as they progress through their training in mobility. If such identifying illumination is desired, it was suggested that an inexpensive arm-mounted light, like those worn by bicyclists, might provide this without the inevitable compromises in cane comfort and performance caused by the lighting of the cane itself.

Evaluation of Snipas Glucose Analyzer.—A preliminary evaluation of the Snipas Glucose Analyzer for blind diabetics was undertaken. It was determined that a majority of the blind diabetics instructed in the use of the device at this center could successfully use it for self-determination of the glucose content of their urine.

Comments from the nursing staff and from the users were forwarded to Triformation Systems in order to provide the manu-

facturers with more subjective data on the performance of their instrument. Experience gained from this evaluation was shared with Dr. Lawrence Scadden who is constructing an evaluation form to be used in a national study of the device. The center is currently participating in this project.

Speech-plus Talking Calculator.—Because of the favorable response of the blinded veterans to the Speech+ Talking Calculator, and its subsequent stocking in Denver, it was felt that a more thorough screening and training program in the use of the device should be created. The research department designed a tape consisting of problems, some with feedback as to the correct answers and others without. The tape provides the veteran with extended practice in solving problems involving all of the basic functions of the calculator, in a format of progressive difficulty. It culminates with a series of "word problems" requiring the user not only to know the operation of the calculator but also to understand the logic involved in mathematical operations.

It was noted that some of the low vision patients with needs for electronic calculators, particularly of the scientific type, could read the large visual display of the Monroe Model 1920. After a brief evaluation it was determined that when possible such a calculator could provide the veteran with a sophisticated alternative to the talking units. Several of these devices have subsequently been issued to veterans.

A listing of the number of clients screened, trained, and issued major prosthetic aids in this reporting period may be seen in Table 5.

TABLE 5.—*Clients Screened, Trained, and Issued Major Prosthetic Aids in this Reporting Period*

Device	Number of veterans screened	Number of veterans trained	Number of devices issued
Sonicguide	a	3	2
Laser Cane	a	1	1
Pathsounder	a	0	0
Stereotoner	0	0	0
Optacon	3	2	1
Speech compressor	a	26	20
Electronic calculator	a	3	3
Closed circuit television	39	13	10

[a]All blinded veterans in the EBRC's programs are shown these devices and screened at that time.

Compression Amplification and Speech Intelligibility in Noise

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This study is designed to investigate the compression characteristics of hearing aids (i.e., distortion characteristics, limiting threshold, transfer function, and transient response) and their influence, if any, on the understanding of speech in the presence of background noise by hearing-impaired individuals. The specific objectives of the project are to compare the three types of compression hearing aids (linear compression, dynamic range compression, and curvilinear compression) to a conventional non-compression aid in measures of loudness comfort, harmonic and intermodulation distortions, and speech intelligibility for soft and loud speech presented in quiet and in noise. Furthermore, the critical variables within a compression amplification system (i.e., attack time, release time, and limiting threshold) will be studied systematically. A test aid with adjustable controls is now being designed. Details will be presented in future reports.

Development of a Hearing-Aid System with Independently Adjustable Subranges of Its Spectrum Using Microprocessor Hardware

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During the 3-month period from July 1, 1976 to September 30, 1976; (namely, until termination of the present contract and the project's incorporation in another VA program) work on the present project was mainly concerned with analog-to-digital and digital-to-analog interfacing, and with problems of stability of the algorithm.

On the hardware side, the analog-to-digital conversion interface has been modified to fit the required spectrum and a digital-to-analog converter has been purchased and interfaced with the Intel 8 Model 80 microcomputer system that is used for this project.

The algorithm developed during the present work is based on the concept of deriving an array of sharp-cut-off digital bandpass filters and combining them in a staircase manner, with different gains for different frequency bands. This in turn is based on the related theoretical (and usually unrealizable) synchronous-type impulse responses. These responses are inherently stable in the limit (i.e., for very long data sequences) but one still has stability problems when dealing with finite data. Therefore, an on-line test routine has been developed for checking stability in cases of insufficient parameter convergence.

Further work on the present project, which is to concentrate on on-line tests of real data, and related clinical tests, will be performed within the framework of the new VA project into which the present contract has been incorporated.

NOTES AND NEWS

ISPO'S NEW "PROSTHETICS AND ORTHOTICS INTERNATIONAL" BEGINS PUBLICATION WITH APRIL 1977 ISSUE

The International Society for Prosthetics and Orthotics (ISPO) is publishing a new journal, Prosthetics and Orthotics International, three times a year. Volume 1, No. 1, appearing in April 1977, contains within its 70 numbered pages "a small number" of the more than 200 papers contributed at ISPO's First World Assembly held in Montreux, Switzerland, and subsequently revised by the authors. The journal's subject matter concerns prosthetics, orthotics, rehabilitation engineering, and associated aspects of orthopedic surgery and other rehabilitation disciplines.

Knud Jansen, M.D., in a presidential Foreword to Volume 1, No. 1, writes that the new journal may be seen as a "resuscitation" of Prosthetics International (originally called the International Journal on Prostheses, Braces and Technical Aids), which ISPO published in four languages in the fifties and sixties when publication was supported by various grants. When the grants, and publication, ceased, communication was maintained by the ISPO Bulletin; Dr. Jansen noted that "the society is most indebted to Mr. A. Bennett Wilson, Jr., who with skill and dedication has produced the ISPO Bulletin through more than 5 years, "since its inception in 1972." Mr. Wilson remains chairman of ISPO's Publication Committee.

The new Prosthetics and Orthotics International is co-edited by John Hughes and Norman Jacobs. Mr. Hughes is Director of National Centre for Prosthetics, University of Strathclyde, Glasgow, Scotland, and is also a member of the Editorial Board.

Members of ISPO receive the journal free. Subscription rate for associate members is $7 (U.S.A.) per annum; for others the subscription rate is $14 (U.S.A.); single members $5 (U.S.A.).

"THE JOINTS OF THE ANKLE" BY VERNE T. INMAN CULMINATES TWO DECADES OF STUDIES

A series of studies at the Biomechanics Laboratory of the University of California has now, after two decades, culminated in

"The Joints of the Ankle." In it Dr. Inman describes studies whose primary objective has been to "sort out the facts from the seemingly discrepant observations reported in the anatomic and clinical literature." These studies, which developed around an exhaustive and critical review of the literature, became over the last 20 years an investigation resulting in new information and concepts not previously available to orthopedists and bio-engineers.

"The Joints of the Ankle" is actually a companion monograph to a future publication, "Human Walking," which will reflect more than 30 years of investigation by the Biomechanics Laboratory. Other companion monographs are also to be expected.

Funding has come from a variety of public and private sources, including continuing financial support from the Veterans Administration beginning shortly after 1945. For support contributing specifically to "The Joints of the Ankle," Dr. Inman credits, in addition to the Federal Work Study Program, The Easter Seal Research Foundation, The Children's Bureau, and the Office of Vocational Rehabilitation, plus support for editorial, stenographic, and art work from the Social and Rehabilitation Service.

Dr. Verne T. Inman, a recipient of the Ph. D. degree in anatomy as well as the M.D. degree, was director of the Biomechanics Laboratory at the University of California, San Francisco, from 1957 to 1973. He is now Emeritus Professor of Orthopaedic Surgery at the same location.

VOCATIONAL AND EDUCATIONAL OPPORTUNITIES DESCRIBED IN BOOKLET FOR THE DISABLED

A new 36-page digest-size booklet, "Vocational and Educational Opportunities for the Disabled," for helping a disabled person find out about and take advantage of existing opportunities, is available from the INA MEND Institute. The Institute is a rehabilitation facility of the Human Resources Center in Albertson, Long Island, N.Y., and the Insurance Co. of North America. Anita Tritell, Vocational Rehabilitation Counseling Coordinator at Human Resources Center, is the author.

The booklet is fourth in a projected series which started with one entitled "General Information for the Recently Disabled." The latest in the series briefly but clearly covers the purpose and philosophy of vocational rehabilitation, describes the types of facilities that exist, and tells how a disabled person can go about securing help and guidance. There is a list of State rehabilitation agencies with addresses, and the text is sprinkled with complete addresses of alternate sources of information which helps to drive home the

message that there is always more than one way to find things out or achieve a goal. There is advice on using the phone book, and a list of the information a person should have on hand when writing or calling.

The INA MEND Institute (acronym is for Medical and Educational Needs for the Disabled) initially intended the booklets in this series to supplement its own programs, but says it made them available to the general public because of their usefulness to the disabled and their families, rehabilitation professionals and educators.

Copies of "Vocational and Educational Opportunities for the Disabled" may be obtained by writing INA MEND Institute, Human Resources Center, Dept. 33, I. U. Willets Road, Albertson, Long Island, New York 11507. The price is $1.25 each, $75 for 100, or $600 for 1000.

BRAILLE BOOK ON AMERICAN ECONOMIC SYSTEM PREPARED BY LIBRARY OF CONGRESS

A braille version of the booklet, "The American Economic System and Your Part in It," has been prepared by the Library of Congress for distribution to the blind. The Library is also reported to be preparing a cassette recording of the same material.

Sources of the material is the Advertising Council, Inc., a nonprofit organization sponsored by the advertising industry. The Council's purpose is to harness the communication skills of the advertising field to improve the public's understanding of the role of the free enterprise system in the American economy.

The Library of Congress donated the translation. Assisting in the project is Frank Cylke, chief of the Division for the Blind and Physically Handicapped at the Library of Congress.

ASME HONORS EUGENE F. MURPHY WITH ELECTION TO GRADE OF FELLOW

The American Society of Mechanical Engineers has honored Eugene F. Murphy, Ph. D., with election to the grade of fellow. Dr. Murphy is director of the Research Center for Prosthetics of the Veterans Administration where he has the responsibilities of planning, coordinating, and evaluating a nationwide program of research, development, evaluation, and education in a wide variety of prosthetics and sensory aids research. Dr. Murphy is a member of this publication's editorial board.

To qualify for advancement to the grade of fellow, ASME requires that a nominee be an engineer with "significant engineering achievements" and "outstanding contributions" to his credit. ASME's citation notes that Dr. Murphy is "a nationally recognized authority and expert in the field of prosthetics and sensory aids for the handicapped."

NATIONAL ACADEMY OF ENGINEERING ELECTS HOWARD D. EBERHART TO MEMBERSHIP

Among the 92 new members selected by the National Academy of Engineering in the spring of 1977 is Howard D. Eberhart, M.S., Professor Emeritus of Civil Engineering, of the Biomechanics Laboratory, University of California at Berkeley. Prof. Eberhart has been well-known to the VA since 1946 for his "pioneering studies of human locomotion, application of structural engineering to prosthetic devices, and leadership of interdisciplinary engineering research," cited by the National Academy of Engineering.

PARALYZED HOSPITAL-DIRECTOR IS NAMED "HANDICAPPED AMERICAN OF THE YEAR"

Joseph J. Panzarella, Jr., M.D., was named Handicapped American of the Year by the President's Committee on Employment of the Handicapped. He had already received two presidential citations for his work in rehabilitation, as well as the Outstanding Disabled Veteran Award from New York State, and the Physician of the Year Award presented jointly by the American Medical Association and the President's Committee.

Dr. Panzarella, 57 years old, has multiple sclerosis and can move only his head. Nevertheless, working with the aid of an attendant, he manages to fill six positions which involve him in practicing medicine, teaching, directing the activities of institutions, and consulting. He is director of Brunswick Hospital Center, Amityville, Long Island, N.Y.; director of the Department of Rehabilitative Medicine at Franklin General Hospital, Valley Stream, Long Island; and professor of physical therapy and other subjects at New York University Postgraduate Medical School, at Nassau Community College and at Suffolk Community College. He also lectures, writes, and travels widely.

His most recent award was not only for his own achievements but also for encouragement and motivation he has imparted to others directly and by example. "Budgeting his time and adapting his duties so that he can perform them"was said to be his technique for this high level of achievement.

UNITED NATIONS TO PROCLAIM THE YEAR 1981 "INTERNATIONAL YEAR FOR DISABLED PERSONS"

A resolution favorably voted by the United Nations General Assembly, in its 31st session, called for an International Year for Disabled Persons to be proclaimed in 1981. "Full participation in society by disabled persons" will be the basic theme. A draft program reflecting the ideas of member states and concerned organizations was expected to be considered by the General Assembly during 1977.

The resolution establishing 1981 as the Year of the Disabled indicated the following broad range of objectives for the program:

Helping disabled persons in their physical and psychological adjustment to society.

Promoting all national and international efforts to provide disabled persons with proper assistance, training, care, and guidance, to make available opportunities for suitable work and to ensure their full integration in society.

Encouraging study and research projects designed to facilitate the practical participation of disabled persons in daily life: for example, by improving their access to public buildings and transportation systems.

Educating and informing the public of the right of disabled persons to participate in and contribute to various aspects of economic, social, and political life.

Promoting effective measures for the prevention of disability and for the rehabilitation of disabled persons.

FOUR MORE OVERSEAS PROSTHETIC-ORTHOTIC WORKSHOPS PLANNED BY WORLD REHABILITATION FUND

Four new workshops, in Egypt, Indonesia, Sri Lanka and Brazil, are planned by the World Rehabilitation Fund. They will bring the number of such WRF workshops to 127 operating in 66 countries. In its first year each workshop is expected to produce more than 500 limbs and braces, using local technicians and materials. Production is expected to increase in later years.

The four latest workshop locations were announced at a 20th anniversary dinner honoring the organization's founder and president, Dr. Howard A. Rusk. Dr. Rusk founded the World Rehabilitation Fund, with Mrs. Albert Lasker and General William Donovan, in 1955. More than 3000 physicians, therapists, and other rehabilitation personnel have been trained by WRF, and the organization has helped provide more than a million prostheses and orthoses.

Initial funding for each center is said to be $20,000, covering the cost of training technicians, permanent equipment, supplies, and WRF supervision for the first year. Host countries provide shop space and agree to provide ongoing expenses in subsequent years. Two local people from the area of each workshop are trained at one of WRF's seven regional training centers, and then are expected to indoctrinate other technicians. WRF supervision is provided for each stage of the workshop's development.

In announcing the plans for the four new prosthetic-orthotic workshops, WRF noted that the $20,000 initial funding would be underwritten by Continental Oil Co. for the Egyptian installation; by Hoffman LaRoche for Indonesia; by the Reader's Digest Foundation for Sri Lanka; and by Becton, Dickenson & Co. for Brazil.

REHABILITATION INTERNATIONAL'S 14TH WORLD CONGRESS SET FOR JUNE 1980, IN WINNIPEG, CANADA

The "Decade of Rehabilitation" proclaimed in 1970 by Rehabilitation International will culminate in R.I.'s 14th World Congress, in June 1980. The Canadian Rehabilitation Council, an affiliate, will organize the Congress with the cooperation of the Workmen's Compensation Boards of Canada and the governments of Canada and the province of Manitoba. Goals of the "Decade" include focusing world attention on the gap between services for, and needs of, physically and mentally disabled people.

ORTHOMEDICS FELLOWSHIP AWARDED AT NYU

Robert F. Pacini, of Belle Vernon, Pennsylvania, is the 1977 recipient of the $2500 Orthomedics Fellowship in Prosthetics and Orthotics. The fellowship is awarded annually to a student in good standing who has completed his junior year of study at New York University's School of Education, Health, Nursing, and Arts Professions.

Described as the first of its kind in these fields, the fellowship established by Orthomedics provides a 10-week clinical affiliation in prosthetics and orthotics with Orthomedics, partially fulfilling the clinical affiliation requirement for the B.S. degree in Prosthetics and Orthotics at NYU.

Mr. Pacini was selected by a faculty committee chaired by Dr. Sidney Fishman, chairman of the department. Orthomedics, of Downey, California, is described as one of the largest providers of prosthetics-orthotics services in the country, with 13 facilities in California and Nevada.

DATA COLLECTED FOR EVALUATION OF SNIPAS GLUCOSE ANALYZER

A glucose analyzer was developed for blind diabetics by a scientific team at the Smith Kettlewell Institute of Visual Sciences, San Francisco, California. This scientific team was the basis for awarding of a Rehabilitation Services Administration grant to establish a Rehabilitation Engineering Center.

Mr. Richard Leclair in the Office of Rehabilitation Engineering and Mr. George Nagers of the Office for the Blind and Visually Handicapped, Washington, D.C., asked 15 rehabilitation centers for the blind to test 15 prototype models of the SNIPAS Glucose Analyzer. These were designed to provide data for an evaluation of the device. A standardized procedure of training and data collection was developed for the test.

The device, intended to permit a diabetic blind person to independently determine the glucose level of a urine sample, signals its results by producing from one to five "beeps." The data reflecting its use by blind diabetic subjects will be analyzed to determine whether certain factors contribute to success in using the device, or restrict its usefulness for certain individuals. The data are also expected to guide the manufacturer (Triformation Systems, Inc., Stuart, Fla.) in modifying the prototype design, if this is found to be necessary.

RECENT PATENTS[a]

Actuator Device for Artificial Leg: John L. Burch, assignor to the United States of America as represented by NASA, Washington, D.C.: A hip-disarticulation type prosthesis is powered by energy drawn from the natural leg, through hydraulic means. It is claimed that the resulting gait will be superior. (Patent No. 3,995,324, Dec. 7, 1976; filed Sept. 12, 1975, Appl. No. 612,965; 12 claims.)

Articulated Master Slave Manipulator: Carl R. Flatau. A manipulator equipped with a number of balance and counter balance concepts. All of a mechanical nature. (Patent No. 3,976,206, Aug. 24, 1976; filed July 16, 1975, Appl. No. 596,228; 9 claims.)

Artificial Foot with Ankle Joint: Werner Haupt, assignor to Otto Bock Orthopadische Industries KG, Duderstadt, Germany. The conventional single-axis ankle/foot has been improved with plastic parts bonded to wood. It is claimed that the plastic strengthens and stabilizes the wood. Component resiliancy permits some motion in all planes, thus reproducing the functions of a double axis or SACH unit. (Patent 4,007,497, Feb. 15, 1977; filed Sept. 3, 1975, Appl. No. 609,995; 2 claims.)

Body Support Means: Reginald Dyson, assignor to G.D. Searle and Co., High Wycombe, England. A combined gel and bead cushion is claimed to provide a favorable pressure distribution. (Patent No. 3,968,530, July 13, 1976; filed Feb. 19, 1974, Appl. No. 443,606 7 claims.)

Check Writing Guide: John E. Keitzer and Betty J. Keitzer, assignors to Betty J. Keitzer. A slotted template permits a blind person to write a check. The template apertures match the appropriate spaces on a standard blank check. (Patent No. 4,003,143, Jan. 18, 1977; filed Dec. 15, 1975, Appl. No. 640,462; 2 claims.)

Compression Sheath for Below-Knee Amputated Limbs: Jan Prahl, assignor to IPOS Gelleschaft Fur Integrierte Prothesen-Entwicklung und Orthopadietechnischen Service mbH & Co., KG, Luneberg, Germany. This sheath develops an increasing squeeze force towards the end of the stump by means of yarn and knit pattern variations. It is claimed that superior blood circulation results. (Patent No. 3,991,424, Nov. 16, 1976; filed June 9, 1975, Appl. No. 584,915; 7 claims.)

Electrically Driven Hand Orthosis Device for Providing Finger Prehension: John P. Ryan, James W. Cowan, Paul K. Sharp, et al.: assignors to Indiana University Foundation, Bloomington, Ill. Quadraplegic patients in powered wheelchairs are able to operate a device providing prehension of the thumb and finger. A touch sensitive switch energizes a motor that drives the splint through a cable. (Patent No. 3,967,321, July 26, 1976; filed Feb. 5, 1975, Appl. No. 547,272; 20 claims.)

Electric Elbow: Carl P. Mason, assignor to Sidney Samole and Myron M. Samole. Harmonic drive gear concepts are used to produce a light and efficient motorized elbow.

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[a] Patents may be ordered by number from the Commissioner of Patents, Washington, D.C. 20231, at 50¢ each.

It is also claimed that the design is sturdy and quiet. (Patent No. 3,987,498, Oct. 26, 1976; filed July 1, 1974, Appl. No. 484,948; 21 claims.)

Invalid Lifting and Walking Device: Dale H. Thomas. A power-operated lifting and walking device which is operated by a handicapped person. After lifting himself to a standing position with a power hoist, the subject can propel the device along a floor using his own muscle power. (Patent No. 3,999,228, Dec. 28, 1976; filed Oct. 10, 1975, Appl. No. 621,423; 5 claims.)

Massaging Support Apparatus: Michael Kosiak. A means of combatting decubiti formation in seated individuals by means of powered rollers. The endless chain of moving rollers within a special seat continuously alters the pressure on the buttocks. It is claimed that blood circulation is thereby improved. (Patent No. 4,011,862, Mar. 15, 1977; filed Nov. 17, 1975, Appl. No. 632,179; 25 claims.)

Myoelectrically Controlled Prosthesis: Charles H. Hoshall, Woodrow Seamone, and Robert L. Konigsbert, assignors to The United States of America as represented by the Secretary of the Navy, Washington, D.C. A myoelectric control system that will provide terminal opening in direct proportion to control signal amplitude. A single site closed-loop servo system is used. (Patent No. 3,735,425, May 29, 1973; filed Feb. 10, 1971, Appl. No. 114,262; 22 claims.)

Orthocasting System: Dennis N. Brown. A means of casting impressions of the bottoms of feet. The cast is then used to construct a rigid foot support. (Patent No. 3,995,002, Nov. 30, 1976; filed Nov. 7, 1974, Appl. No. 521,889; 4 claims.)

Orthopaedic Appliances: Pierre Rabischong and Jean Pierre Louis Bel, Montpellier, France. Assignors to Institut National de la Sante et de la Recherche Medicale, Paris, France. An inflatable prosthesis to enable paralytics to stand, differing from other versions of this concept in its smaller use of compressed gas and greater use of mechanical locking features. (Patent No. 3,993,056, Nov. 23, 1976; filed Jan. 21, 1976, Appl. No. 651,033; 17 claims.)

Orthopedic Brace (Orthosis): Walter Kuehnegger, assignor to Otto Bock Orthopedic Industry, Inc., Minneapolis, Minn. A brace aimed to correct difficulties in the higher thoracic region. The device is similar to a Milwaukee brace with the addition of more members in the anterior-posterior direction. (Patent No. 3,945,376, Mar. 23, 1976; filed Dec. 12, 1974; Appl. No. 532,067; 10 claims.)

Paper Money Identifier: Frank J. Marchak. Photocells are arranged to examine currency. Audible signals indicate the denomination of paper currency to blind persons. It is claimed that the position of the bill within the apparatus is unimportant to the process. (Patent No. 3,906,449, Sept. 16, 1975; filed Sept. 11, 1974, Appl. No. 504,931, 16 claims.)

Pressure Distribution Pad Assembly for Wheelchairs: Matthew Hall, assignor to Everest and Jennings, Inc., Los Angeles, Calif. A sandwich type of cushion involving three pads of which the center is the most dense. Cutouts in the center pad are placed in zones of maximum pressure. Both stability and pressure characteristics are claimed superior with this device. (Patent No. 3,987,507, Oct. 26, 1976; filed Aug. 25, 1975, Appl. No. 607,360; 3 claims.)

Prosthetic Device for Holding Golf Clubs: William K. Frenzel. An attachment to a prosthetic arm device permits the handle of a club to be gripped in a secure and controllable

manner. A wide range of clubs may be readily grasped without alterations to the club handle. (Patent No. 3,965,491, June 29, 1976; filed Jan. 7, 1976, Appl. No. 647,058; 8 claims.)

Prosthetic Guitar Pick: Evan P. Gallagher. A guitar pick is strapped to the lower arm with a belt arrangement. (Patent No. 3,992,975, Nov. 23, 1976; filed Oct. 8, 1975, Appl. No. 620,848; 6 claims.)

Polysensory Mobility Aid: Larry S. Moricca and Ronald H. Stroer, assignors to Zipcor Inc., Fort Wayne, Ind. A device resembling a pair of glasses yields a combination of auditory and tactile stimulation signals signifying the location, distance, and brightness of a visible object with respect to the viewer. Photosensitive devices serve as sensors. Stimulus frequency is tied to brightness. Distance is obtained through triangulation. (Patent No. 3,993,407, Nov. 23, 1976; filed Sept. 19, 1975, Appl. No. 615,060; 15 claims.)

Wheelchair-Mounted Control Apparatus: Alden C. Simmons, James T. McFadden, and Robert S. Bennett, assignors to Whittaker Corp., L.A., Calif. A wheelchair control system using a skin pickup to control drive motor speed, reclineability, and external devices such as a TV tuner. (Patent No. 3,993,154, Nov. 23, 1976; filed Nov. 5, 1975, Appl. No. 629,033; 14 claims.)

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A Note on the Ratio Between Tensions in the Quadriceps Tendon and Infra-Patellar Ligament, R. E. D. Bishop and R. A. Denham; Engng. in Med., 6(2):53-54, Apr. 1977.

Percutaneous Implant Devices, Vert Mooney, S. Andrew Schwartz, Andrew M. Roth, and Michael J. Gorniowsky; Ann. Biomed. Engng., 5:34-46, 1977.

The Possibility of Structural and Functional Restitution after Spinal Cord Injury: A Review, Elizabeth Puchala and William F. Windle; Experimental Neurol., 55:1-42, 1977.

Postural Changes and Aerodynamic Forces in Alpine Skiing, Kazuhiko Watanabe and Tatsuyuki Ohtsuki; Ergonomics, 20(2):121-131, 1977.

Sequential Muscular Contraction, K. M. Jackson, J. Joseph, and S. J. Wyard; J. Biomech., 10:97-106, 1977.

A Simple Force Platform, Flemming Bonde-Petersen; Europ. J. Appl. Physiol., 31:51-54, 1975.

Supplement to Bibliography on Muscle Receptors: Their Morphology, Pathology, Physiology, and Pharmacology, Earl Eldred, Herbert Yellin, Mark DeSantis, and Cedric M. Smith; Experimental Neurology, 55(3) Part 2, June 1977.

Voice Controlled Wheelchair, James A. Clark and Robert B. Roemer; Arch. Phys. Med. Rehabil., 58:169-175, Apr. 1977.

Walking Speed as a Basis for Normal and Abnormal Gait Measurements, T. P. Andriacchi, J. A. Ogle, J. O. Galante; J. Biomech., 10:261-268, 1977.

Welding Thermoplastics, Neal R. Donaldson and Michael J. Quigley; Ortho. & Pros., 31(1):51-53, Mar. 1977.;

CALENDAR OF EVENTS

Helen Keller World Conference on Services to Deaf-Blind Adults, New York, N.Y., Sept. 11-15, 1977.

First International Conference on the Evaluation of Biomaterials, Université Louis Pasteur, Strasburg, France, Sept. 26-28, 1977. (Under auspices European Society for Biomaterials. For information: Dr. J. L. Leray, U18-Inserm, 6 Rue Guy Patin, F 75010 Paris, France.)

Western Orthopaedic Association, Annual Meeting, Colorado Springs, Colo., Oct. 1-5, 1977.

Optical Society of America, Annual Meeting, Royal York Hotel, Toronto, Canada, Oct. 9-15, 1977. (For information: J. W. Quinn, OSA, 2000 L Street, N.W., Washington, D.C. 20036.)

American Occupational Therapy Association, Annual Conference, San Juan, Puerto Rico, Oct. 17-21, 1977.

Fourth Conference and Exhibition on BioEngineering, Budapest, Hungary, Oct. 24-28, 1977. (For information: Scientific Society of Measurement and Automation, 1372 Budapest V, Kossuth Lajoster 6-8, Hungary.)

American Orthotic and Prosthetic Association (AOPA) National Assembly, Sheraton-Palace, San Francisco, Calif., Oct. 25-29, 1977.

American Academy of Physical Medicine and Rehabilitation, and American Congress of Rehabilitation Medicine Convention, Miami, Fla., Oct. 30-Nov. 4, 1977.

American Speech and Hearing Association, Chicago, Ill., Nov. 2-5, 1977.

30th Annual Conference on Engineering in Medicine and Biology, IEEE EMB Group, Los Angeles Hilton, Los Angeles, Calif., Nov. 5-9, 1977. (For information: Patricia I. Horner, Suite 404, 4405 East-West Highway, Bethesda, MD. 20014, 301-657-4142.)

Annual Meeting, Engineering in Medicine and Biology, ASME/AEMB, Los Angeles Hilton, Los Angeles, Calif., Nov. 6-10, 1977. (For information: American Society of Mechanical Engineering, 345 E. 47th St., New York, N.Y. 10017.)

Winter Annual Meeting, ASME, Hyatt Regency and Atlanta Hilton Hotels, Atlanta, Ga., Nov. 27-Dec. 2, 1977. (For information on Bioengineering Program: Dr. Ed Grood, Dept. of Orthopedic Surgery, University of Cincinnati Medical Center, 231 Bethesda Ave., Cincinnati, Ohio 45267.)

Acoustical Society of America, Meeting, Miami Beach, Fla., Dec. 13-16.

The Second International Conference on Legislation Concerning the Disabled, Manila, the Philippines, Jan. 1978. (Sponsor is Rehabilitation International; host is the Philippine Foundation for the Disabled, Inc., with support of the Philippine Government.)

American Association for the Advancement of Science, 144th National Meeting, Washington, D.C., Feb. 12-17. (For information: AAAS, 1776 Massachusetts Ave., N.W., Washington, D.C. 20036.)

Orthopaedic Research Society, Dallas, Tex., Feb. 21-23, 1978.

American Orthopaedic Foot Society*, *Annual Meeting, Dallas, Texas, Feb. 23, 1978. (For information: Nicholas J. Giannestras, M.D., 2415 Auburn Ave., Cincinnati, Ohio 45219.)

American Academy of Orthopaedic Surgeons, Dallas, Tex., Feb. 23-28, 1978.

World Federation of Occupational Therapists, 7th International Congress, Tel Aviv, Israel, Mar. 12-18, 1978. (For information: 7th International Congress of the World Federation of Occupational Therapy, P.O. Box 16271, Tel Aviv, Israel.)

The Society for Biomaterials, San Antonio, Tex., April 26-May 3, 1978.

2nd International Symposium for Facial Prostheses, Oak Hill Motor Inn, San Antonio, Tex., May 4-6, 1978. (Participants: Audie Murphy VA Hospital; South Texas Medical Center, Bexar County, Texas.)

World Confederation for Physical Therapy, 8th International Congress, Tel Aviv, Israel, May 28-June 2, 1978. (For information: Organizing Committee, 8th International Congress WCPT, P.O. Box 16271, Tel Aviv, Israel.)

Acoustical Society of America, Kingston, R.I., June 13-16, 1978.

International Rehabilitation Medicine Association, 3rd World Congress, Basel, Switzerland, July 2-7, 1978. (For information: Dr. W. M. Zinn, Thermes, CH-7310 Bad Ragaz, Switzerland.)

6th International Symposium on External Control of Human Extremities, Dubrovnik, Jugoslavia, Aug. 28-Sept. 1, 1978. (For information: Yugoslav Committee for ETAN, P.O. Box 356, 11001 Beograd, Jugoslavia.)

American Academy of Physical Medicine and Rehabilitation and **American Congress of Rehabilitation Medicine Convention**, New Orleans, La., Oct. 29-Nov. 3, 1978.

Optical Society of America, Annual Meeting, Jack Tar Hotel, San Francisco, Calif., Oct. 30-Nov. 3, 1978. (For information: W. J. Quinn, OSA, 2000 L Street, N.W., Washington, D.C. 20036.)

American Orthotic and Prosthetic Association (AOPA), National Assembly, Town & Country Hotel, San Diego, Calif., Oct. 31-Nov. 4, 1978.

Conference on Engineering in Medicine and Biology, Atlanta, Ga., Nov. 6-9, 1978. (For information: American Society of Mechanical Engineering, 345 E. 47th St., New York, N.Y. 10017.)

American Speech and Hearing Association, San Francisco, Calif., Nov. 18-21, 1978.

ASME Winter Meeting, San Francisco, Calif., Nov. 26-30, 1978.

Rehabilitation International Medical Commission, 4th International Seminar, Southampton, United Kingdom, 1978. (For information: Prof. Dr. Karlheinz Renker, Gesellschaft fur Rehabilitation in der DDR, Harz 42-44 Halle (Saale), German Democratic Republic.)

International Association for Prevention of Blindness Conference, Kyoto, Japan, 1978. (For information: Dr. W. J. Holmes, 1013 Bishop St., Honolulu, Hawaii 96813.)

6th Pan Pacific Rehabilitation Conference, Seoul, Republic of Korea, May/June 1979. (For information: Pyung K. Moon, M.D., vice-president, Korean Society for Rehabilitation of the Disabled, 15-San, Sinchon-dong, Sudaemoon-ku, Seoul, Korea.)

World Federation of the Deaf, 8th Congress, Sofia, Bulgaria, Aug. 1979. (For information: Secretariat General, Union of the Deaf of Bulgaria, 3 Bd Ul Zaimov, Sofia, Bulgaria.)

Optical Society of America, Annual Meeting, Holiday Inn and Americana Flagship Hotel, Rochester, N.Y., Oct. 7-12, 1979.

American Orthotic and Prosthetic Association (AOPA), National Assembly, Hilton Palacio Del Rio, San Antonio, Tex., Oct. 23-27, 1979.

American Academy of Physical Medicine and Rehabilitation and **American Congress of Rehabilitation Medicine Convention**, Honolulu, Hawaii, Nov. 11-16, 1979.

ASME Winter Meeting, New York, N.Y., Nov. 25-30, 1979.

Rehabilitation International, 14th World Congress, Winnipeg, Canada, June 22-27, 1980. (For information: Canadian Rehabilitation Council for the Disabled, Suite 2110, One, Yonge St., Toronto, Ontario M5E 1E8, Canada.)

(Tentative) American Orthotic and Prosthetic Association (AOPA), National Assembly, Toronto, Ontario, Canada, 1980.

International Society for Prosthetics and Orthotics (ISPO), the Netherlands, 1980.

EDITOR'S NOTE

The "Index to the Bulletin of Prosthetics Research, BPR 10-25 and BPR 10-26" will not appear in this issue. In order to better serve the needs of our readers, we are revising the format, content, and style of the Index. The two issues mentioned above will be indexed in the Index which will appear in the BPR 10-28, Fall 1977 issue.

Earl A. Lewis, Editor

NOTICE TO CONTRIBUTORS

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