KINEMATIC STUDIES OF NORMAL UPPER-EXTREMITY MOVEMENTS TO BE COMPARED WITH PATIENTS WITH POWERED ASSISTANCE

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During the past five years, a research project has been under way at the Texas Institute for Rehabilitation and Research to develop simplified, functionally efficient externally powered orthotic systems for the severely physically impaired individual. The objective has been to restore, to a maximum degree, functions which have been lost because of disease or injury.

The Institute is the department of rehabilitation of Baylor University College of Medicine in Houston, Texas. While it is primarily a teaching and research center, there is a bed capacity for 55 patients and facilities for 105 out-patients who are seen in the various clinics.

Although a number of patients are seen who require deformity preventive or corrective equipment, the major portion of the work is with those suffering from quadriplegia as a result of traumatic injuries or other neuromuscular disorders. Here we are faced with the need to restore useful function as simply and efficiently as possible.

The most practical way of doing this is by means of external power. The pneumatic system is used, primarily because, in our opinion, it meets the criteria of simplicity and efficiency for this type of patient.

Basically two types of patients are seen who need external power. One has permanently lost all finger and wrist movement resulting from a spinal cord lesion at the C-5, 6 level, and the other has lost all function in the upper extremities except that of raising and lowering the shoulder girdle.

For the first group, an externally powered finger prehension orthosis with wrist friction joint has been developed (Fig. 1). The major components in the system are the power source, power actuator, and controls.

This study was supported in part by a research and demonstration grant RD-1564, from the Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, Washington, D. C.

The McKibben muscle substitute is used for the power actuator and carbon dioxide is employed as energy for the system. To control the unit, a simple mechanical valve was designed which consists of a spring-loaded arm capable of sufficiently depressing a small silastic tube to stop or permit the flow of gas under pressure. This system permits the patient to obtain smooth, gradated movements of the externally powered functions, proportional to the controlling movement applied.

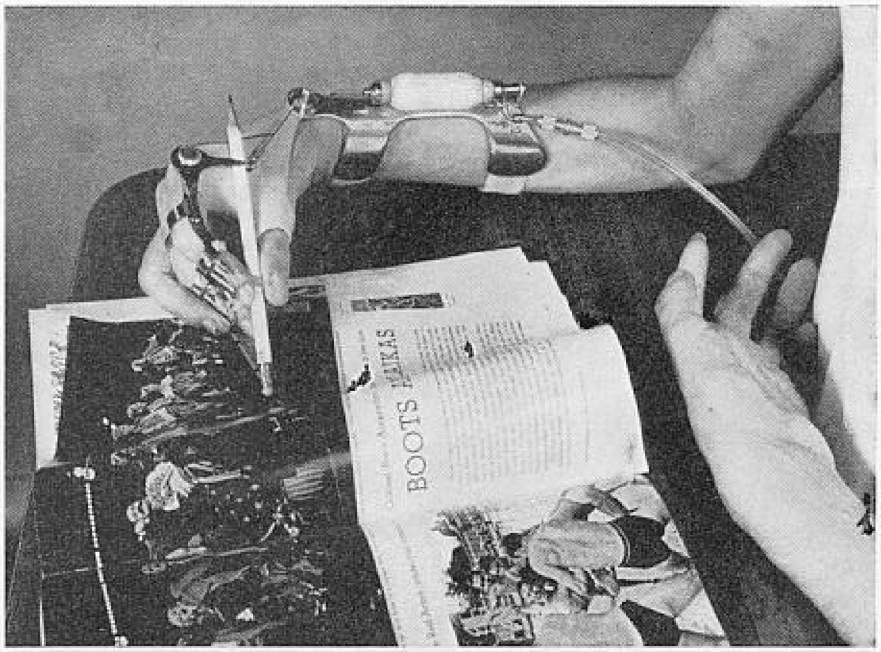

Figure 1. An externally powered finger prehension orthosis with wrist friction joint is used to restore function for the patient with a spinal cord lesion at the C-5, 6 level

Since its development, this externally powered prehensing orthosis has been adapted to thirty-two patients, including some bilateral adaptations. The unit is adapted to the dominant extremity and the controls are located where it is most convenient for the patient.

For patients in the second group, an externally arm unit has been developed (Fig. 2). Here again, the patient's musculoskeletal structure is utilized as the biomechanical part of the device. Two power actuators are used in this system, one which flexes and supinates the forearm, and the other which abducts the extremity. These are activated by the patient in combination or separately according to the movement he is performing.

The abduction unit utilizes the vector parallelogram principle which permits horizontal movements independent of the powered elevation movement. A coil spring is incorporated into the system and serves to minimize the gravity forces imposed by the extremity, thereby assisting the power actuator in working to its fullest efficiency.

The elbow flexion unit is linked to the abductor by means of a swivel arm. The proximal end of the power actuator is located slightly above the fulcrum of the elbow joint and the distal end is attached near the radial side of the orthosis. Thus, when contracted, it produces the combined motion of elbow flexion and supination.

While the results of these efforts have been termed reasonably successful in numerous clinical applications, the need for further improvement is still of great importance. Just a few years ago, the program of assisting functions with external power was quite limited. Today, however, it is known that useful and worthwhile functions can be greatly restored. With further study, it is believed continued advances will be made.

Figure 2. A smooth, synchronized movement of the upper extremity is in the shoulder joint and scapular area

To determine where technical improvements should be made in the overall externally powered system, it is now evidnet that it is necessary to understand, in depth, the complex, synchronized musculoskeletal action of normal upper-extremity motions, including associated head and torso movements.

The most important physiological linkage in a human being is that between the eyes and the hands. Our objective is to study this vital relationship in greater detail, so we may better understand the functional requirements of the mechanical components and how they should be integrated with the patient's residual body function.

Currently a detailed kinematic study is being made of the velocity and acceleration of the biomechanical functions of the upper extremities as purposeful activities of daily living are performed.

By photographing normal subjects performing basic activities from a sitting position, accurate digrams of upper-extremity movements can be made. At a later date, we will follow the same procedure using patients with powered assistance, and these diagrams will serve as the basis for comparative analysis.

In photographing the normal subjects, a 35-millimeter movie camera was placed 20 feet from the subject. Two mirrors were positioned at 45-deg. angles to show three perspectives of the subject simultaneously: front, side, and top (Fig. 3). Time clocks of one second and one-hundredth of a second provided references for the velocity and acceleration of each motion.

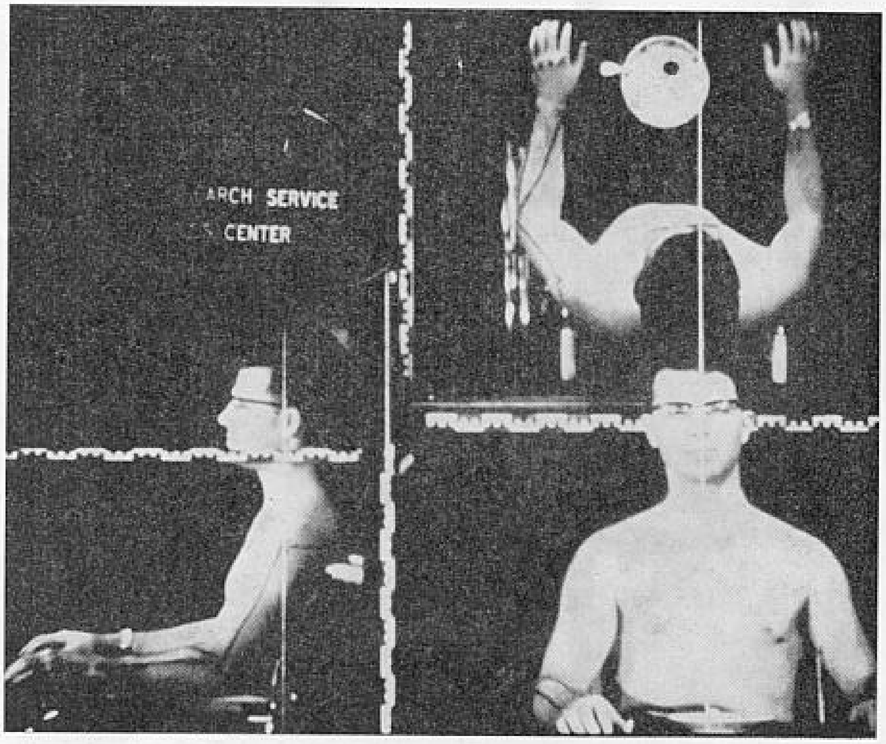

Figure 3. Three perspectives of the subject are seen in each frame of the film. This enables a more careful analysis of the pattern of each action

A black felt pen was used to identify land marks on the subject at the metacarpophalangeal joints, the styloid processes, the lateral epicondyle of the elbow, and the shoulder joint.

Nine normal subjects have been photographed performing five basic motions: table to mouth feeding, hair grooming, page turning, writing, and diagonal reaching. These activities encompass three of the most important levels of hand movement; table, mid-torso, and head area. To achieve a representative sample of human physiology so that an accurate mean could be established, subjects were chosen who ranged from slightly obese to tall, thin individuals.

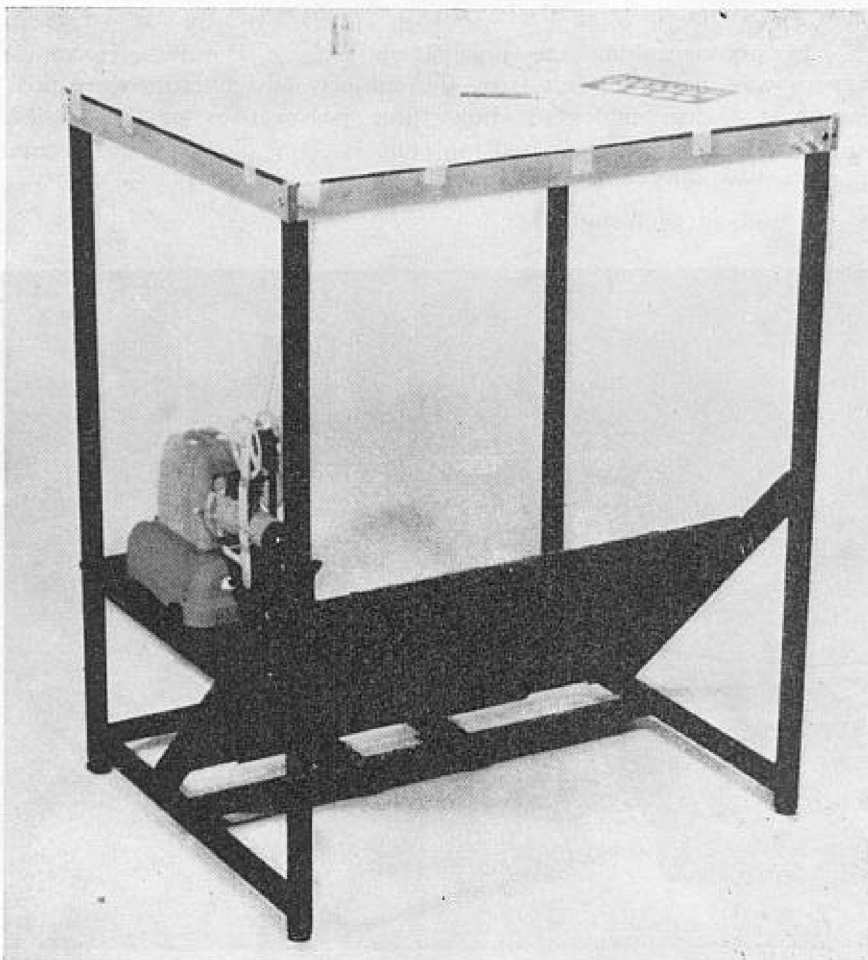

Figure 4. A special mirror arrangement and a standard film strip projector are used to project the image onto a glass screen in the manual analytic method

For comparative purposes, two identical sequences were taken of each subject, first without orthotic equipment, and secondly, with the arm orthosis, but without external power, to determine if the equipment hinders normal upper-extremity movement.

In determining the best method for analyzing this volume of film data, experimentation has been done with two techniques — manual analysis, and, more recently, computer processing.

With the manual method, a special mirror arrangement and a standard film strip projector are used to project the three perspectives of the subject onto a glass screen which also serves as a table. This screen is covered with translucent acetate to facilitate the plotting (Fig. 4).

The selected land marks are identified in each view in black on the acetate as the film is advanced frame by frame. Once the action is completed, the points are connected with red lines to identify the pattern of movements, and the relating angulation and acceleration between each point. The timing is determined by the number of frames in each complete action.

Photograps are then taken of the completed diagram which is superimposed over both the beginning and end motions for each activity.

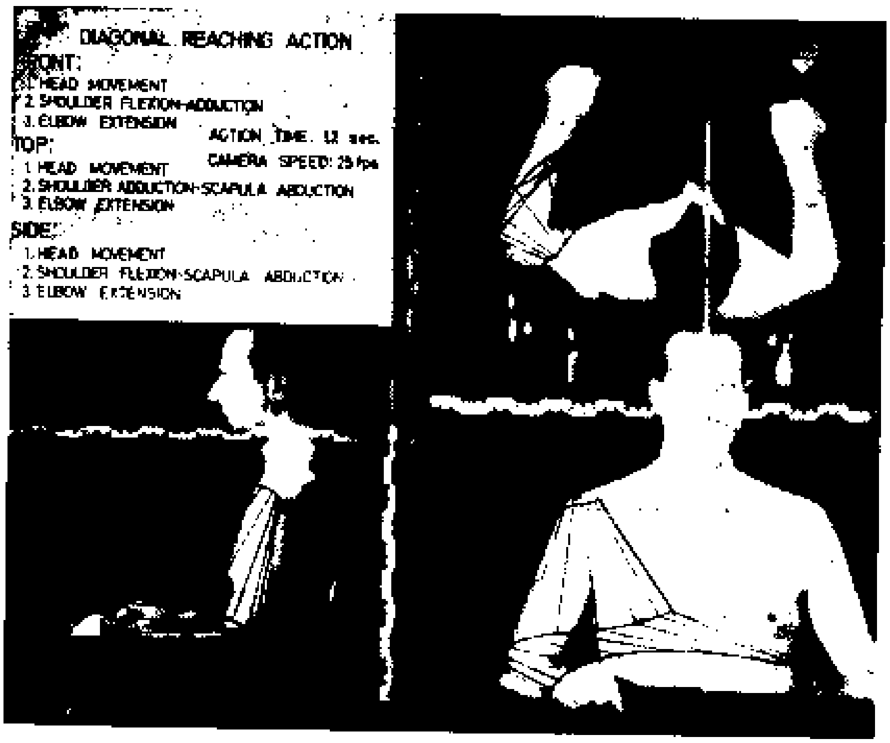

Figure 5. The completed diagram is superimposed over the beginning motion of the diagonal reaching activity

In analyzing this data, only those motions whose points of reference are clearly visible from beginning to end in each view are selected In the diagonal reaching activity (Fig. 5) the head movement is visible throughout the front view, as are shoulder flexion and adduction and elbow extension. The top view enables measurement of head movement, shoulder adduction, scapula abduction and elbow extension. From the side view, data are retrieved on head movement, shoulder flexion, scapular abduction, and elbow extension.

By superimposing the same diagram over the end motion of the diagonal reaching activity (Fig. 6), it is apparent that major actions occur in the shoulder joint and scapular area. The forearm is flexed in the beginning of the action, then extended slightly.

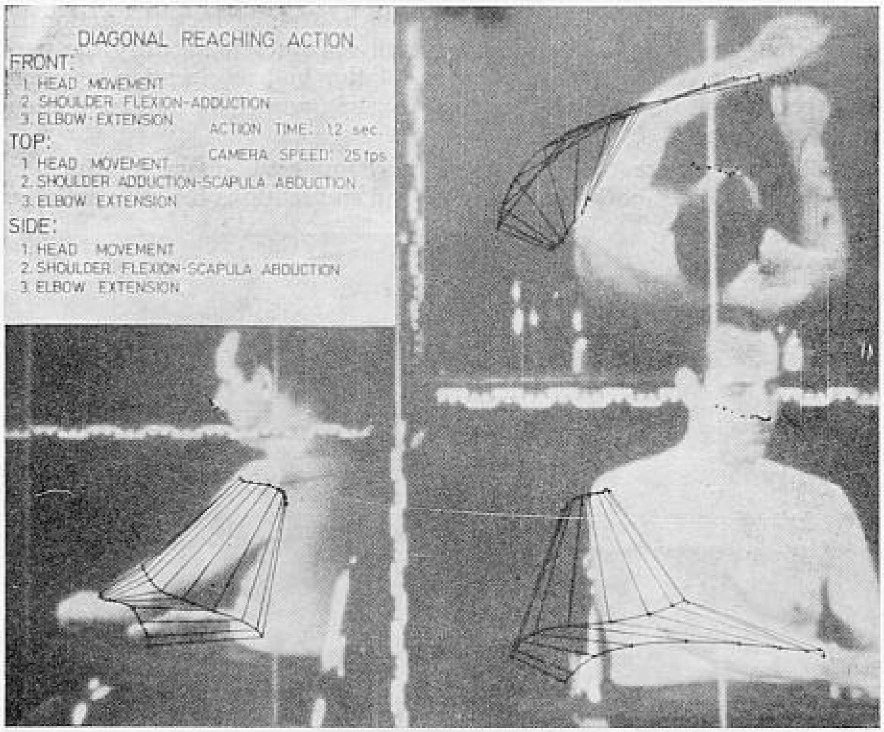

Figure 6. Analysis of the diagonal reaching activity shows the major function is in the shoulder joint and scapular area.

Further analyzing this actioh, the correspondence of acceleration and terminal deceleration between the head and forearm is noted. The forearm accelerates rapidly in the beginning of the action, then slows as it reaches the terminal point and the head moves similarly. The hand remains in a neutral position throughout the activity.

As the detailed analysis of these diagrams is extendend, measurements will be taken of the angle between the lines which are separated by equal time intervals but changing distances (Fig. 7).

One of the most important functions to be restored for the severely functionally impaired individual is that of self-feeding. This actions is a combination of many synchronized joint motions, more so perhaps than any of the activities being studied.

Head movement, abduction and elevation, internal rotation and shoulder flexion are combined with elbow flexion, humeral rotation, and supination of the hand in this action (Fig. 8).

The diagrams for two subjects performing self-feeding have been completed. Figure 9 illustrates the result of the first subject's diagram having been superimposed beside that of the second subject.

Comparison of the two diagrams shows that the pattern of sequential movements is nearly identical in acceleration, velocity and angulation. The only difference is in the size of the diagram, a factor which is determined by the subject's physical stature.

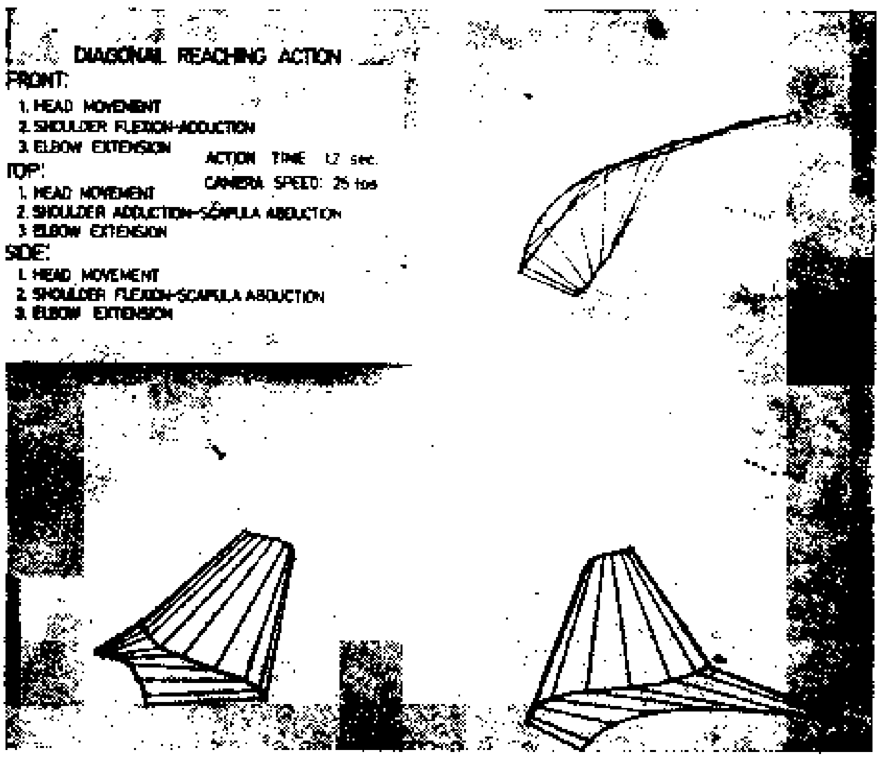

Figure 7. The diagram will be used to measure the angle between each of the selected land marks

As indicated previously, the possibilities of using computer processing in analyzing the film data also are being explored. The land marks have been digitized with a Telecordex X-Y converter to furnish data for a machine-readable format which is used as the input for a computer program. Programs have been written which accept these data, perform the necessary mathematical conversions, and provide a magnetic tape, which, in turn, is the input for an IBM X-Y plotter.

Transparencies are made of the computer plots and superimposed on an enlarged picture of the subject (Fig. 10). The time interval is 1/25 of a second between each point of reference.

An important advantage of using this method is that the data, one recorded, are always available for further analysis. This method is still being explored, however, and the plots of diagonal reaching are among the first attempted. Once these motion descriptive data are in the computer file, a variety of relationships can be computed including position vectors, velocity and acceleration patterns, etc. Statistical comparisons among subjects also can be made with ease.

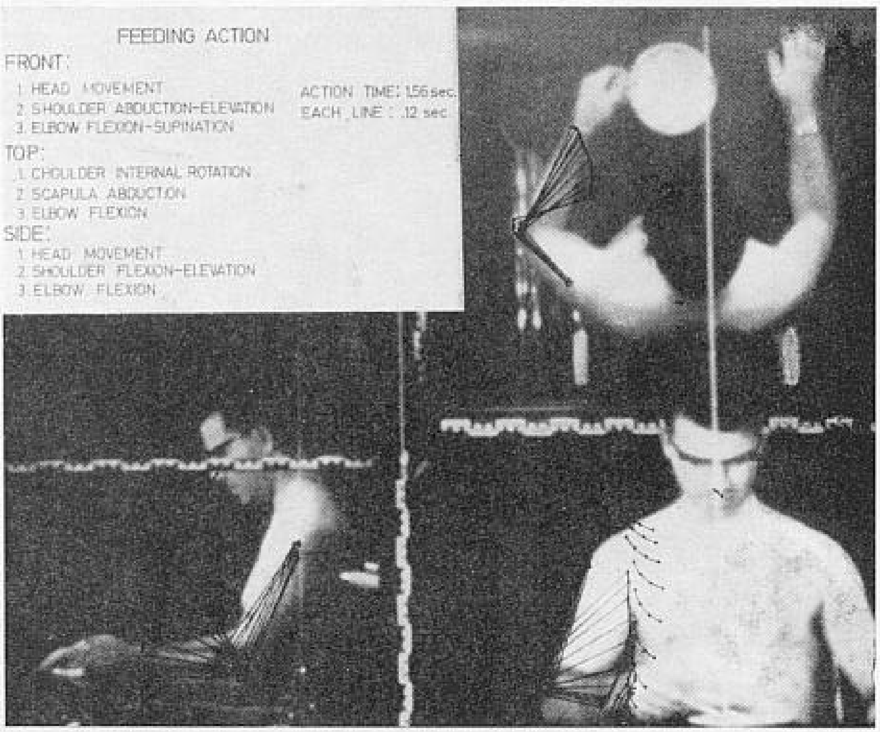

Figure 8. The feeding action is a combination of many synchronized joint motions

With either method, the analysis of the remaining normal subjects' motions will continue until we have an accurate pattern of movement for each. At that time, mean values will be established for each of the five daily living activities. These will then be compared with the movement patterns of the patients using powered assistance.

Although we still are in the preliminary stages of this motional analysis, it is evident that it will broaden our understanding of the biomechanical relationship between joints as purposeful activites are performed.

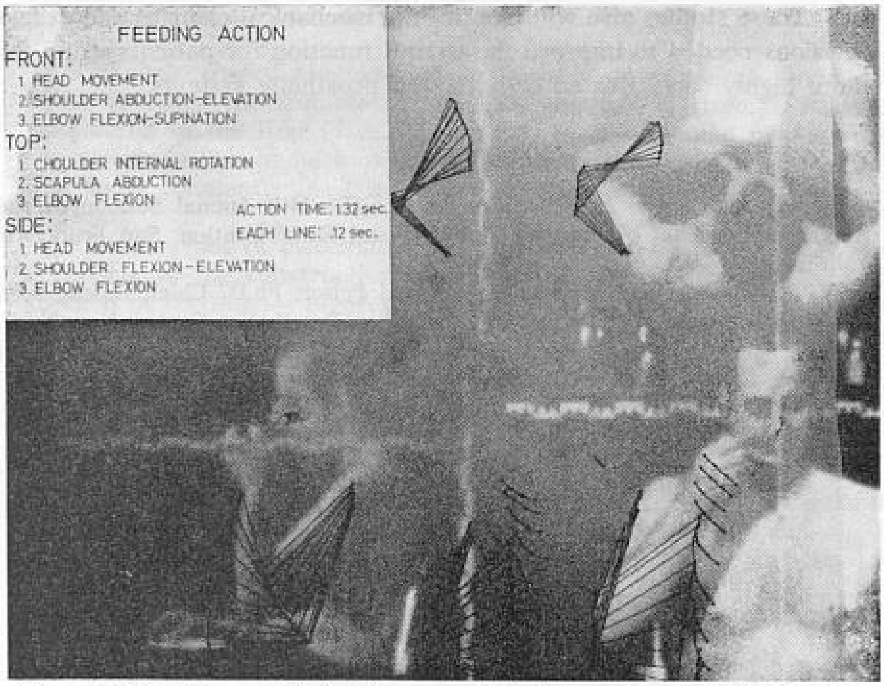

Figure 9. The first subject's diagram (left) is superimposed beside that of the second subject. Comparison reveals the only differences are determined by the subject's physical stature

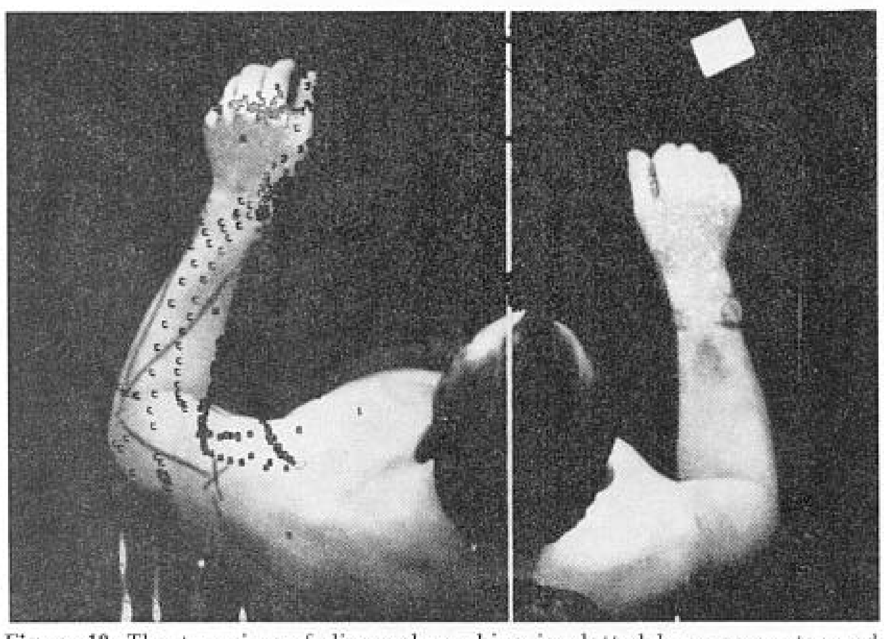

Figure 10. The top view of diagonal reaching is plotted by a computer and superimposed over the photograph to indicate the pattern of movement

These studies also will identify the mechanical changes and design revisions needed to improve the overall function for patients using the more highly sophisticated orthotic and prosthetic systems.

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This paper was presented in part at the 44th Annual Session of the American Congress of Physical Medicine and Rehabilitation, San Francisco, California.

Acknowledgment is given to Edward Peizer, Ph.D., Chief, Bioengineering Research Center, Veterans Administration Prosthetics Center, New York, and his staff for their assistance in obtaining the film data, and to Allan Levy, M. D., Director of the Baylor Medical Computing Science program, for his timely assistance.