ELECTRONIC AND ELECTROMECHANICAL AIDS FOR THE HANDICAPPED

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ELECTRONIC AND ELECTROMECHANICAL AIDS FOR
THE HANDICAPPED

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CHAPTER I

INTRODUCTION

1-1. General Discussion of the Problem

In the July 1970 issue of the IEEE Spectrum, Marc Elecion (1), quoted the following from J. L. Flanagan's editorial in the special issue on Communication Aids for the Handicapped, IEEE Transactions on Audio and Electroacoustics, December 1969:

> Among the gratifying aspects of engineering work are the opportunities to apply scientific knowledge to the betterment of man. Such opportunities are nowhere better represented than in the area of communication aids for the handicapped.

Flanagan also wrote that:

> ... very often the engineer - the man best equipped to devise useful communication aids is ignorant of the capabilities of the handicapped individuals whom this technology might serve. On the other hand teachers and therapists who are generally quite familiar with the human factors are not skilled in electronic design. Obviously each group may learn from and help each other. In many cases the successful development of a sensory aid - from the identification of a problem susceptible to solution through engineering conception and implementation to testing under field or classroom conditions requires a close partnership of interested professionals from both camps.

Flanagan's words might well have been applied to the whole field of electronic and electromechanical aids for the handicapped. For in this fertile field, often the engineers who are capable of developing a given device do not know the need for such a device and the man who has a need for the device does not know that such a device is feasible.

It is apparent that the development of electronic and electromechanical aids for the handicapped will require the services of dedicated engineers.

Many of the devices now contain and in the future will involve sophisticated electromechanical systems. Others will involve only the bare minimum of instrumentation.

Regardless of the degree of sophistification required, the engineer is in an excellent position to make a meaningful contribution to the betterment of the handicapped segment of America's society.

Another facet of the problem concerns the economics of the development of devices to aid the handicapped. It does very little good for one to develop a very useful device for the handicapped if the price of the device is so high that it mitigates against the widespread acceptance and use of the device.

It appeared that the area of electronic and electromechanical aids to the handicapped was worthy of attention and it was selected as a topic for this thesis.

The thesis considers two main areas. The first is a literature survey of electronic and electromechanical aids for the handicapped. In order to limit the scope of the survey, only the following topics were considered:

Electronic and electromechanical aids for the blind.

Electronic and electromechanical aids for amputees.

Electronic and electromechanical aids for the training of the mentally retarded.

System and bandwidth considerations of the feedback paths employed by electronic and electromechanical aids for the handicapped.

Because of special interests, the design, construction, and testing of electronic teaching aids for the mentally handicapped were chosen for an in-depth study.

1-2. Delineation of the Problem

Despite the often well-publicized so-called, "breakthroughs", in the area of electronic and electromechanical aids for the handicapped, one notes that in his everyday life, he rarely comes in contact with a handicapped person who has benefited from the use of such a device.

This immediately raises the question as to whether or not legitimate "breakthroughs" have been made and if so why they are not in more general usage.

Thus, it seemed that a comprehensive literature study of electronic and electromechanical aids for the handicapped was in order. The survey should answer such questions as: what are the present types of electronic and electromechanical aids for the handicapped? What are the present trends in the development of such devices? What are the economics involved? Why are these aids not in general usage?

The results of a preliminary literature survey indicated that very little work had been done in the development of low cost training aids for the mentally handicapped.

The major developments in this area consisted of complicated and relatively expensive teaching machines.

The concept and application of teaching machines are fine except for the fact that their cost and, thus, subsequent scarcity mitigated against their widespread use.

It was, therefore, decided that the development of a simple inexpensive training aid was in order and that such a device would fill a need in today's society.

Thus, after the design and construction of the training aid, a suitable experiment must be designed in order to evaluate the effectiveness of the device.

Simplicity and economics must not be the only criteria for the training aid, it must also fulfill a need of society.

It is at this point that the engineer is at a disadvantage, since he has been trained to expect nice orderly solutions to problems.

At the onset of the problem it became painfully apparent that, as is true in most learning processes, the process of evaluation was a slow one and that there would not in general be concise answers.

As a matter of fact, the device may well turn out to fulfill a need in society that the engineer did not know existed at the time he conceived the device.

1-3. Organization of the Thesis

Chapter II contains the results of a literature survey of past, present, and proposed electronic and electromechanical aids for the blind.

Chapter III contains the results of a literature survey of past, present, and proposed electronic and electromechanical aids for amputees.

Chapter IV contains special topics on man-machine interfaces related to the special feedback requirements imposed on electronic and electromechanical aids for the blind and the amputees.

Chapter V contains the results of a literature survey of past, present, and proposed electromechanical aids for the mentally retarded.

Chapter VI discusses the design and construction of the audiograph.

Chapter VII outlines the experimental procedures used in the evaluation of the audiograph.

Chapter VIII contains the summary and conclusions.

CHAPTER II

ELECTRONIC AND ELECTROMECHANICAL AIDS FOR THE BLIND

One of the more widely publicized facets of aids to the handicapped concerns electronic and electromechanical aids for the blind. It was inevitable that man would attempt to externally compensate for the loss of the important sense of sight.

These devices have in general followed two major paths of development. The first, which is still in the very early stages of development, makes use of auxiliary devices to sense the surroundings which are then injected directly into the nervous system of the user. At the present time, these devices have had no serious development (2).

The second path, and the one that has to date proved to be the most fruitful, utilizes other physical senses to convey the necessary information to the brain. The skin is the only other part of the body that matches the eye in transmitting sensory information to the brain. It does not have the eyes resolution, but it can give a reasonable reproduction of an object traced by point-to-point methods. The hearing sensory organ is also used to convey information to the brain. It has been most useful, of course, in transmitting the spoken word to the brain. It also finds application as a final detector in those devices used in terrain avoidance.

This is accomplished by changing the physical characteristics of the terrain into an electrical signal which is used to modulate a carrier. The pitch and the amplitude of the carrier signal are varied in accordance with the terrain controlled modulation. The output device is either a speaker or a set of headphones.

Prior to discussing electronic and electromechanical aids for the blind it is in order to mention those aids which are not of an electronic or electromechanical nature.

The first and probably the most widely used device to aid the blind came in the form of a cane which is used by the blind to avoid obstacles in their path and to aid in staying on the correct course. The modern long cane is still the most useful device in conveying information to the user concerning the nature of his surroundings.

The seeing eye dog finds widespread use and has freed many of the blind from the confines of his home and are of great value from a physical and psychological standpoint.

The above mentioned aids to the blind have widespread usage and serve as a reference point in the evaluation of electronic and electromechanical aids for the blind.

The electronic and electromechanical aids for the visually handicapped may be lumped into three broad categories. First, there are those devices which are intended to aid the blind to read or otherwise assimulate information from the printed page. Second, there are those devices which may be broadly classed as direction following and terrain avoidance devices. Third, there are those devices which attempt to enable the blind to "see" through the use of their skin. The latter devices are useful in reading as well as giving the user a two-dimensional picture of his surroundings.

The advent of microelectronics has given new hope to the visually handicapped by spurring attempts to develop more compact, lightweight, and economical devices.

The first general category of devices or systems are those that are used to convey information from the printed page to the blind, and have their roots in the Braille system which was invented by Louis Braille in 1829. The Braille system is one in which the characters are represented by raised dots and the information is transmitted to the brain by the finger through the use of the tactile sense. It is interesting to note that none of the most modern developments have enabled the blind to approach the reading speed of those blind who use the Braille system. With this system a properly trained person can read 200 words per minute. The paramount disadvantage of the Braille system is that only about 10 per cent of the blind have learned to use this system (3).

The second obvious disadvantage is that the printed word must be translated into Braille characters.

When one considers that the normal Braille translator operates at a speed of 12 words per minute and that an ordinary 400 page novel, when translated into Braille becomes four volumes, each the size of a volume of the Encyclopaedia Britannica, it becomes apparent that the translation problem is a serious disadvantage of the Braille system.

The advent of high speed computers and printing devices have to a large extent helped to overcome this disadvantage. Although a glance at almost any local library will reveal that their supply of books translated into Braille is extremely limited. The need to translate the printed page into Braille has led to the development of various devices.

The first was Fournier D'Albers optophones of 1912 and 1920, which converted the printed words into tones or clues (4). Most of the modern reading devices utilize the basic idea of the optophones. One such device is the visotactor which converts the printed word by means of optical scanning devices into either a tactile stimulation by way of vibrating reeds or into a nine tone code. The duration of the tones are a function of the blackness of the image. The accuracy of the visotactor is about 90-95 per cent in converting the printed word to information that can be understood by the blind.

A device which is related to the one given above was invented by John Linvill, head of the Electrical Engineering Department at Stanford (5). He invented the device for his blind daughter, Candy. This device consists of an array of pizeo electric bimorph reeds about the size of a pencil point that are activated by photo cells contained in an optical probe that is moved over the printed page. The probe uses eight photoreaders for height and five photoreaders for width and picks up the variations in the letters and, thus, controls the vibrations of the reeds which transmit the image to the fingers.

After fifteen hours of practice one can learn to read at a rate of about 25 words per minute. This compares to 100 words per minute by the Braille system. But, it has the obvious advantage that the book need not be translated into Braille.

One other device that is related to this system of conveying information is the Visograph which scans the original page and produces a large embossed replica in metal foil.

A different approach to the problem has been taken by the American Foundation for the Blind of New York City (6). They have taken the route of the talking books and have attempted to overcome one of the basic disadvantages of talking books, namely, that the speaking rate is approximately 170 words per minute while the reading rate is normally about 280 words per minute. They accomplish this by means of harmonic compression, which operates in the following manner.

The sighted reader reads the text into a microphone and amplifier. The speech is then fed into a parallel bank of 36 bandpass filters which separates it into its different frequency components. The output of the filter bank is sent to 36 frequency dividers which divide the frequencies from the narrow band filters by one-half. The signals are then sent to filter networks to remove the distortion. They are then combined into a single signal and are recorded on magnetic tape. The frequencies of this signal are one-half of those contained in the original signal. The tape is then replayed at double the recording speed; thus, the frequencies are returned to the original values. Consequently, the syllabic rate is doubled but the voice pitch is the same and one avoids the typical Donald Duck chatter that one obtains when you play normal speech at a rapid rate. There was at the time this article was published (1967) only one of these machines in existence and there were no plans of building another. The current model would cost approximately $25,000 to duplicate and, since there is as yet no commercially oriented application, the device will not be duplicated.

John J. Depress (7) reported that the comprehension of the constant frequency compressed speech becomes difficult at about the same rate as the Donald Duck effect reaches a discomforting level in the same speech.

The second class of devices, better known as terrain avoidance devices, in general consist of a sensing device which is carried by the blind person and which converts information concerning the terrain to either tactile or audio stimulation.

The first such device was reported by V. Twerskey in a 1941 edition of Electronics (8). These devices either use light or ultra sonic sound as the carrier. Changes in the terrain modulate this carrier and the returned signal is demodulated and the information is presented to the blind person through use of an audio or a tactile signal. They are very useful in the detection of objects, but do not give indications of the presence of sudden drops in the terrain. Some of the devices sound warnings whenever the object is six feet away, the amplitude increases as the object is approached, and at two and one-half feet a beep is added to the warning of the individual.

On January 4, 1971, a brief article in the Wichita Eagle announced the formation of Adams Enterprises, a company that will specialize in the production of aids for the handicapped (7). The article indicated that Mr. Adams had designed, tested, and was ready to go into the production of a sonar cane.

The stem of the device consists of a hollow aluminum cane about five feet long. At the bottom of the cane a sonar transmitter is mounted. The sound receiver is mounted near the handle of the cane. The sound is transmitted to the operator of the cane by means of stereophonic earphones. The operator locates and determines the shape of objects in his path by swinging the cane from side to side. The maximum possible range of the unit is about 15 to 20 feet. However, the average range of the test models has been in the neighborhood of eight feet. The cane is powered by six penlight batteries. It is expected that the production models will weigh less than two pounds and that they will cost in the neighborhood of $75.00.

To my knowledge, this is the first such device to go into production and to be placed on the market.

Stanford Research (10) Center in Melo Park and the Presbyterian Medical Center in San Francisco are developing tactile image convertors in which pictures from a videocon camera or a group of photocells are reduced to a simple dot-by-dot sketch on a particular area of the skin. As was true in the Linvill device, the dot pattern is transmitted to the skin by means of reed ticklers which are activated by the photocells or the videocon camera.

Both suffer the disadvantage that the picture is two dimensional and considerable interpretation is required of the individual. Stanford is using the Linvill fingertip array while the Presbyterian Medical Center is using a 20 x 20 array on a man's back (11).

Some recent developments in this area have indicated that three dimensional vision may be to a limited extent possible (12). In this experiment a television camera was used as the sensing system and the man-machine interface consisted of four ten-by-ten matrices of biomorph reeds. The subjects involved were able to make three dimensional predictions of familiar objects. They were also able to sense which object was in front of another. The subjects were both blind and sighted.

The results of the experiment showed no significant differences in their performance. The author reported that this device had a visual acuity of 20/600.

It should be noted that the experiment was conducted under laboratory conditions and that this device is not portable. If, however, further experiments indicate that it is of sufficient value to the blind, it seems reasonable to expect that a way will be found to make a portable unit of this nature.

Mr. J. C. Swail, noting the many attempts made to develop travel aids for the blind, became concerned that these items would give the user information concerning his surroundings, but would not give the user information as to the direction of his travel (13). For example, suppose an individual wished to walk across a large open field, a parking lot, etc. Mr. Swail was motivated by the fact that many reports had reached him concerning the use by blind people of certain transistor radios in aiding them to walk in a straight line. He investigated and found that the people were using the antenna pattern of the ferrite antenna in ordinary radios as a nulling device. The signal source is the radio station that the radio is tuned to. The radio is held in the hands then rotated until a null is reached. The null is sensitive to the direction that the person is traveling and, thus, may be used as a direction sensing device. He converted a number of radios to this type device by installing a special circuit in the IF section which detected the presence or absence of a carrier which, in turn, was used to vary the pitch of an audio tone or was used to change the tactile stimulation of a reed vibrator.

The device was tried out in Montreal and Ottawa, and, after the trial, was modified to alleviate many of the complaints that he received. The device was capable of discriminating in direction to five degrees. It was not really very successful in the test and could be used only after some training.

At this point, the author of this thesis became curious as to why it was necessary to have the radio as a direction finder. A much simpler device could be devised through the use of a compass with directional alarms which would sound whenever one deviated from the preset course. It should be noted that the blind person first had to make the choice of his course which he would presumably do based upon past knowledge of the terrain. He would then set this course into his direction seeker prior to beginning his walk. Whenever he strayed beyond the tolerances of deviation he would be given a suitable alarm.

Another device used to aid the blind and deaf was the special doorbell, which was developed in England (14). Basically, the special doorbell consisted of many loops of wire strung throughout the house which were activated at a given frequency whenever the doorbell was rung. The tone was detected and presented to the user by means of a tactile vibration and told the person whenever his bell was rung.

It appears at the present time that much of the effort in this area has been based on "seat of the pants" engineering, and that much more basic research into the problem needs to be done (3).

The bloom seems to be off of the bush as a number of people in the area have given up trying to compete. The market is at best marginal and, as true in other fields, low cost, reliability, durability, and utility remain supreme. The requirement of low cost seems to mitigate heavily against some of the more elaborate schemes which were mentioned.

CHAPTER III

BIO-ELECTRIC PROSTHETIC CONTROL SYSTEMS

Electronic and electromechanical aids to amputees have developed along the line of bio-electric prosthetic control systems. Initial work in this area showed great promise and a number of prosthetic control systems have been developed.

By and large the devices which have been developed are concerned with arm and wrist amputees.

A casual glance might indicate that the movement of one's limbs is a rather simple act. However, more insight as to the complexity of the system may be gained by viewing it from the control system standpoint. For example, consider the human upper extremities as shown in Figure 1.

One notes the presence of various parallel feedback paths. One of the more noticeable components of the feedback is the visual feedback. The eye transmits information to the brain which gives positional and velocity information concerning the limb. One notes that even when this important feedback path is disrupted (blindness for example) the human is still capable of operating his limbs with a great deal of dexterity.

The feedback that describes kinesthetics (sensation of movement, position, touch, temperature, and pressure) is comprised of sensory nerve receptors in the skin muscles and tendons. It is apparent that the degree of amputation controls the number of feedback paths that

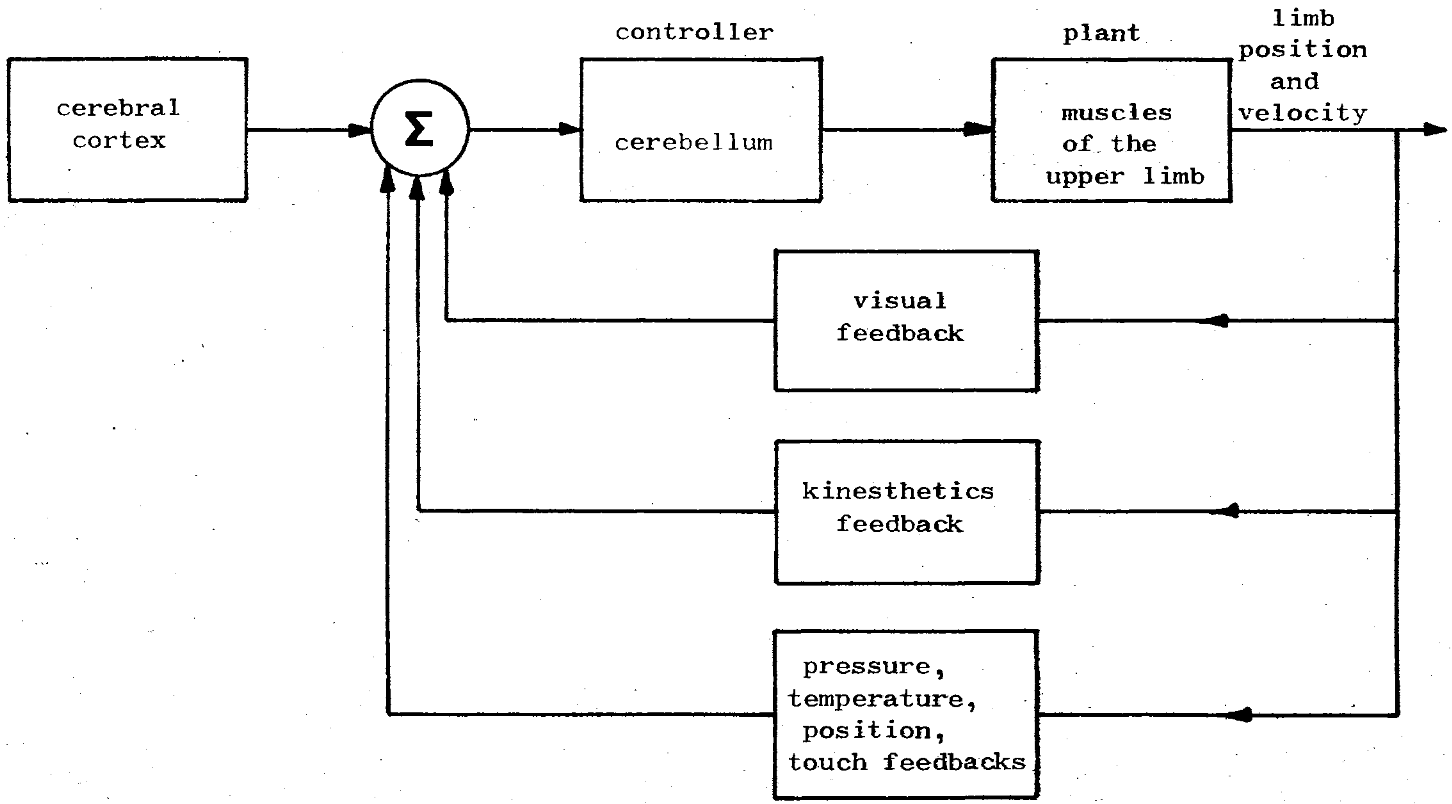


Figure 1. Block Diagram of the Upper Limb Control System

remain. Visual information becomes very important in these cases, since a hook or other such device would not have any other feedback path except the visual.

The first step in the direct control of prosthetic devices consisted of sensing the bio-electric potentials from the skin and then using these signals to drive the device. The major source of trouble with this type of control is the man-machine interface. An electrode jelly is used to reduce the impedance between the electrode and the dry skin. Unfortunately, in many cases continued use of the jelly causes skin irritation. In addition, the exact nature of the signals required to produce even simple movements is not known.

To date, several types of control systems have been developed to stabilize the response of the prosthesis by velocity and force feedbacks. But, one area that needs more attention is the use of feedback that is directly coupled to the human. For example, an amputee that picks up an object can only tell if he has grasped it properly through the use of visual feedback. This area is still relatively new and the current push in micro-electronics is sure to influence developments in this field.

The first working model of a bio-electric controlled prosthesis was produced in 1955 by C. K. Battye, J. Whillis, and A. Nightingale in London, England, at Guys Medical School (15). No attempt was made to commercialize the device, it was used only to prove feasibility. The system was essentially a bang, bang control system with hysteresis being a desirable feature of the system. A fairly large signal is required to activate the system but a less signal will hold it in the activated position and a signal whose amplitude is below the lower threshold will deactivate the device. See Figure 2. One notes that this is an open loop system. No attempt was made to include any feedback other than visual.

The Russians, in 1957, developed the Russian myo-electric powered hand (16). It was designed for use by a medium below the elbow amputee. The device had two functions available, the grasp and the release. The drive mechanism, located in the hand, operated at a fixed speed and the force of grasp was changed only by timing. The index finger, middle fingers and thumb are motor driven to give a three-way chuck type grasp. Friction rings allowed the hand to be rotated passively about the long axis of the forearm. A block diagram is shown in Figure 3.

The amplifiers receive inputs from either the extensor or flexor muscle groups remaining in the arm. The outputs of the amplifiers are used as inputs to a bang, bang control system. There is no velocity or force feedback; thus, no means of preventing excessive current drain in the motor stall position. The grasp between the tip of the thumb and index finger is 35.3 to 52.9 ounces.

A three-yaw-chuck type hand prosthesis was developed in 1962 by the Manchester College of Technology in England (17). See Figure 4. Note that this is an external type feedback system with the feedback mechanism incorporated in the driving unit. The feedback signal is derived through the use of carbon bonded rubber on all palm surfaces. This material changes resistance in proportion to the force applied. This signal is looped into external feedback of the system, thus, requiring more effort from the amputee for a large closing force than for a small closing force.

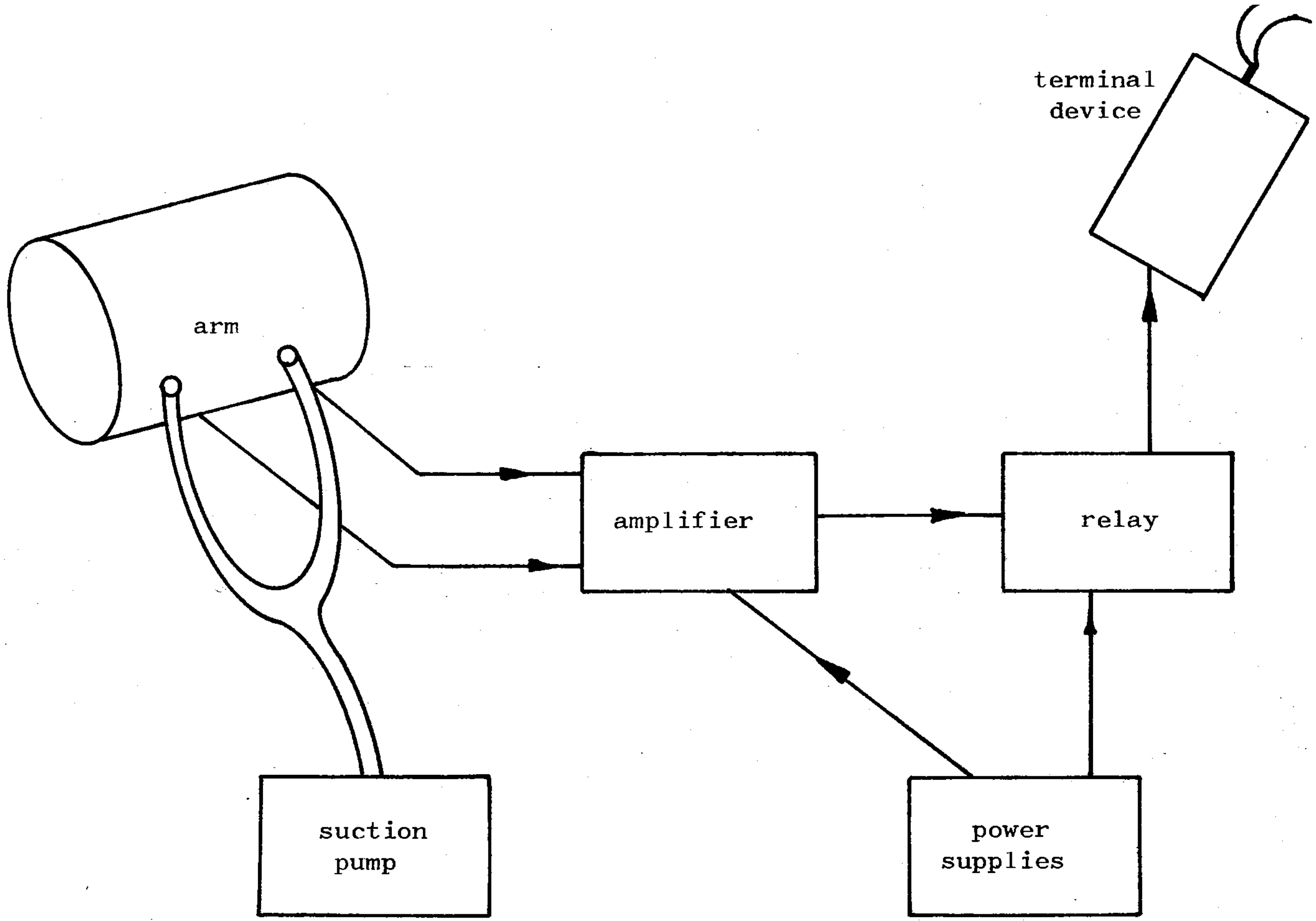


Figure 2. Block Diagram of the Guy's Bio-Electric Controlled Prosthesis

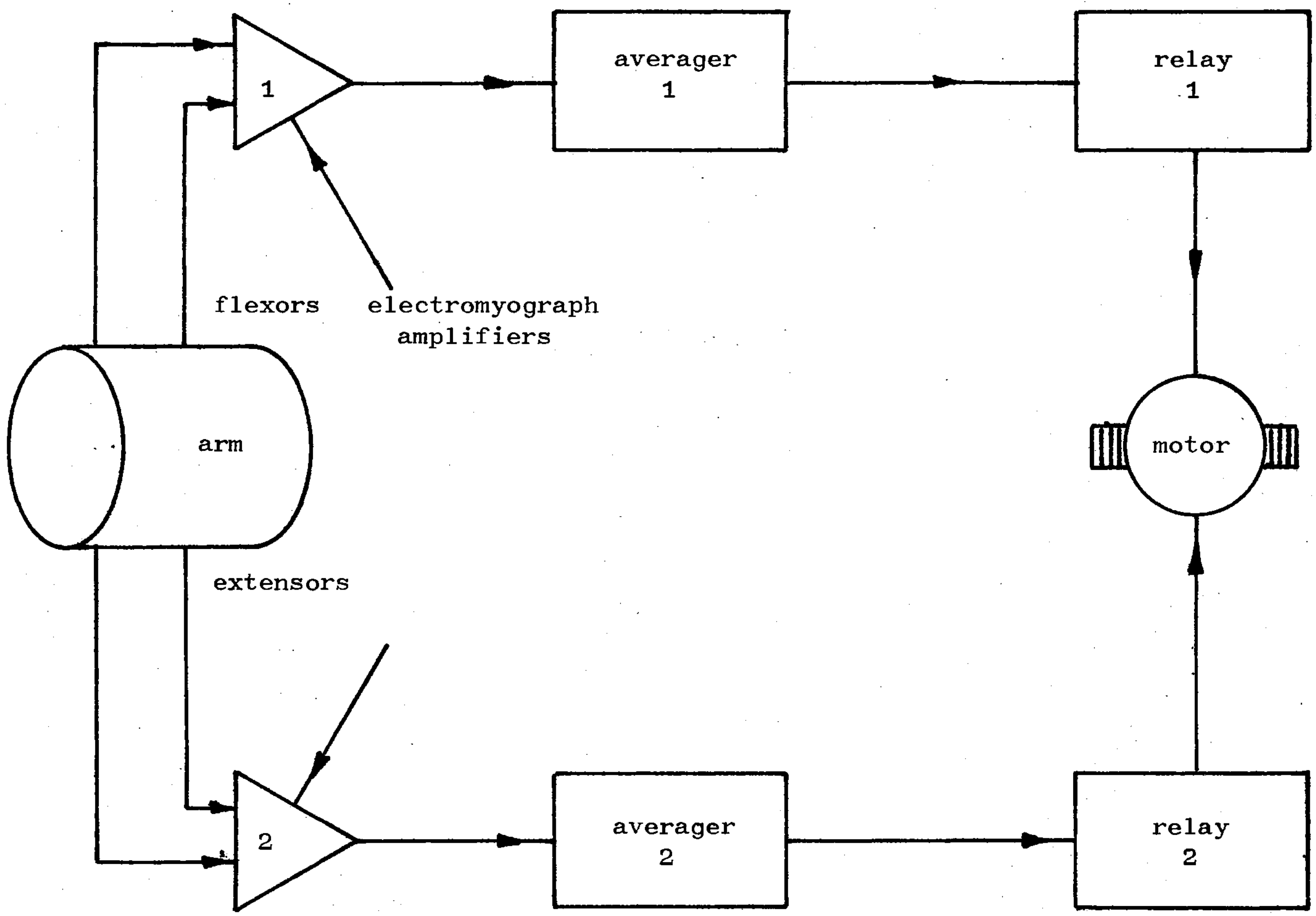


Figure 3. Block Diagram of the Russian Myo-Electric Powered Hand

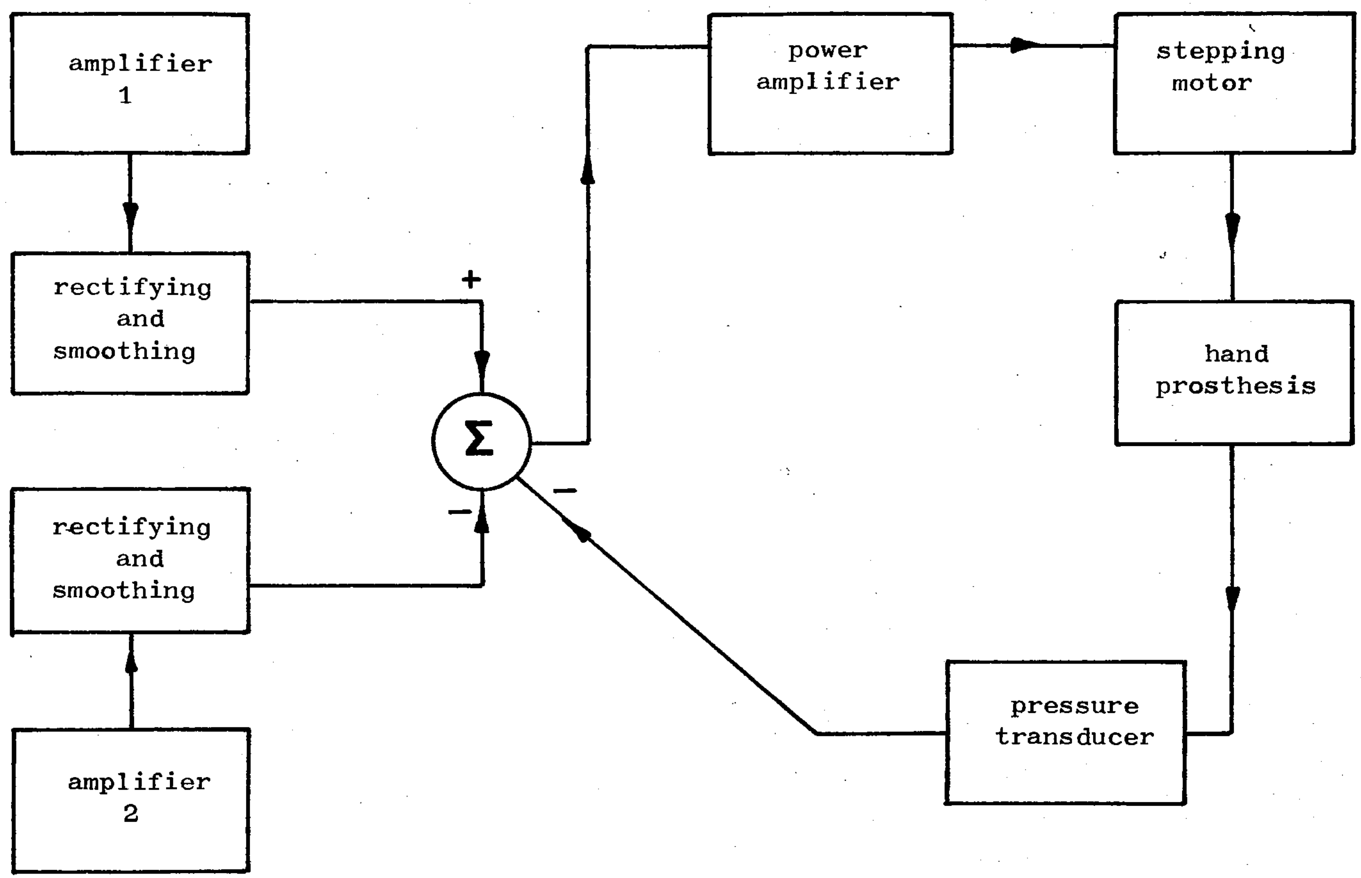


Figure 4. The Manchester Hand Prosthesis

The grasping function is performed by a small stepping motor which moves backwards or forward depending upon the intput signal. The motor is attached to a cable which draws the hand to the closed position. The hand is returned to the open position through the use of springs. Springs are also used in the fingers to allow the handling of irregular objects.

In 1965, the Boston arm was developed by Dr. Ralph Alter and R. N. Rothchild (18). They used muscle potentitals from the biceps and triceps to control an above-elbow prosthesis. The control system (see block diagram Figure 5) does not control the terminal unit but merely drives the elbow unit. The signals from the biceps and triceps are picked up by electrodes and are used as inputs to differential amplifiers. The output of the differential amplifiers are sent to a demodulator, which is essentially an absolute magnitude circuit. The two signals are then subtracted and sent to a low pass filter. The output of the filter is used as the input to a control system which has both velocity and force feedback. The force feedback is derived from strain gages which are applied to the elbow of the prosthesis. A clutch is placed in the drive train of the arm, thus allowing the motor to move the arm up and down, locking it into position whenever the motor is off.

One quickly notes as he examines the various systems used for bioelectric control of prosthetic devices that almost all of the feedback provided is of an external nature; i.e., acts on the device rather than on the man. One primary reason for this is the type of signal available to activate the devices.

When the cerebral cortex of the brain sends a message down the nerve fibers, nerve impulses or action potentials are developed across

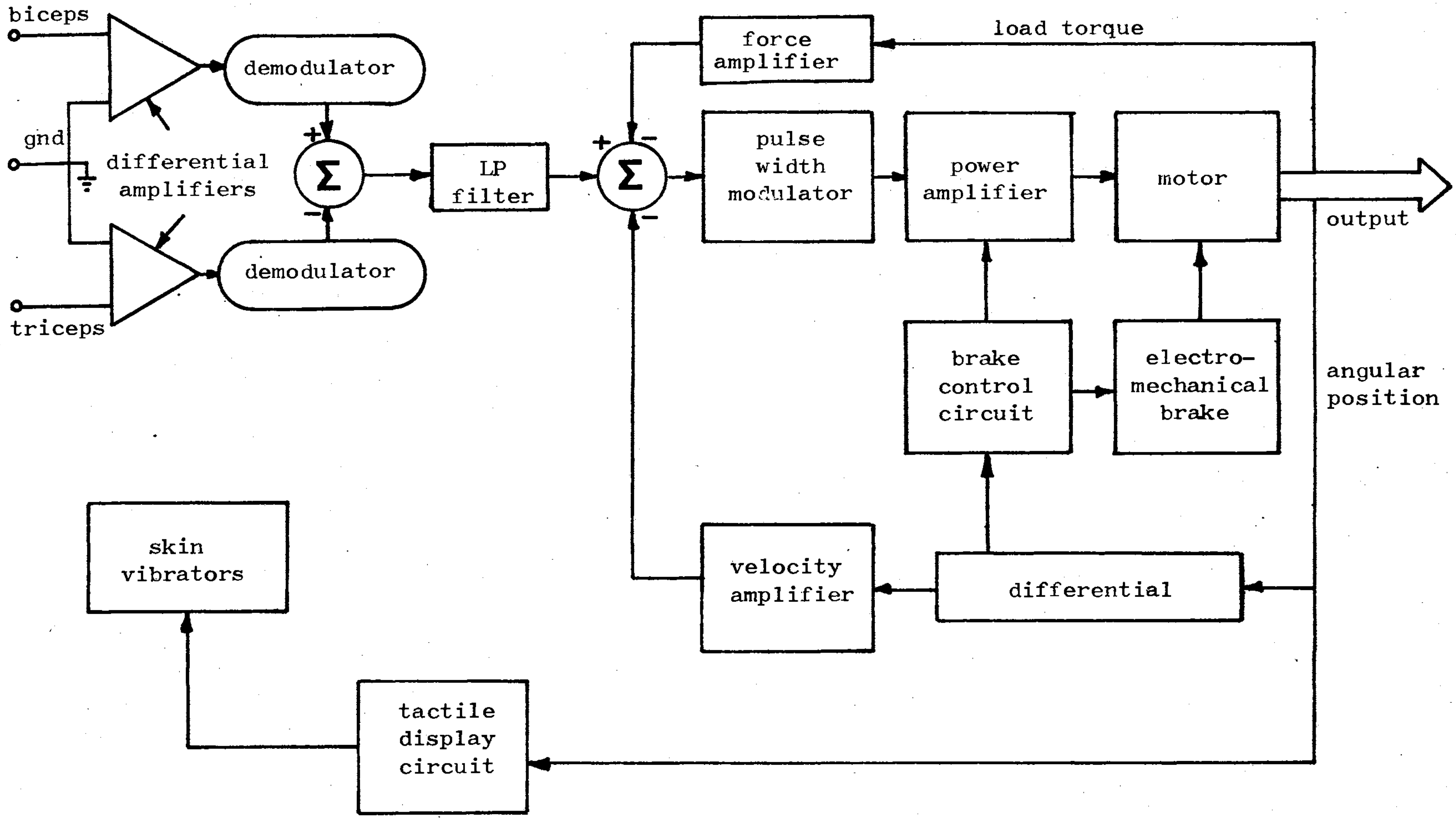


Figure 5. Block Diagram of the Boston Arm

the cell membrane. When the impulse reaches a motor and plate, a chemical substance is released and the muscle contracts. Since the contraction of the skeletal muscles create skin potentials, these potentials may be used as the bio-electric signals. The EMG signals are collected, amplified, and smoothed to provide an imput to a servo control system. The control systems are of necessity of the bang, bang type. In most instances any feedback applied is used to stabilize the external system and, thus, is not too helpful to the amputee in determining the position or the correctness of the grasp of his device.

Thus, though the technology has advanced to the stage where it is feasible to construct an electromechanical prosthetic device that would duplicate the degrees of freedom of the movements of the normal limbs, the technology has lagged in the all important man-machine interface. Much of the work in this area should be concentrated on defining the signals that may be derived from the man. Another area of interest is the development of better types of feedback to aid the amputee in the control of the device. Special interest will be shown to those types of feedback that act on the man rather than upon the device.

CHAPTER IV

MAN-MACHINE INTERFACES AND BANDWIDTH CONSIDERATIONS

4-1. The Transfer Function

The exact configuration of the biological control systems of the body are not known. Certain flow diagrams may be drawn based upon the assumption of a lumped parameter system. These diagrams do not tell the full story and much more basic research will be needed to develop a satisfactory model for the biological system (14).

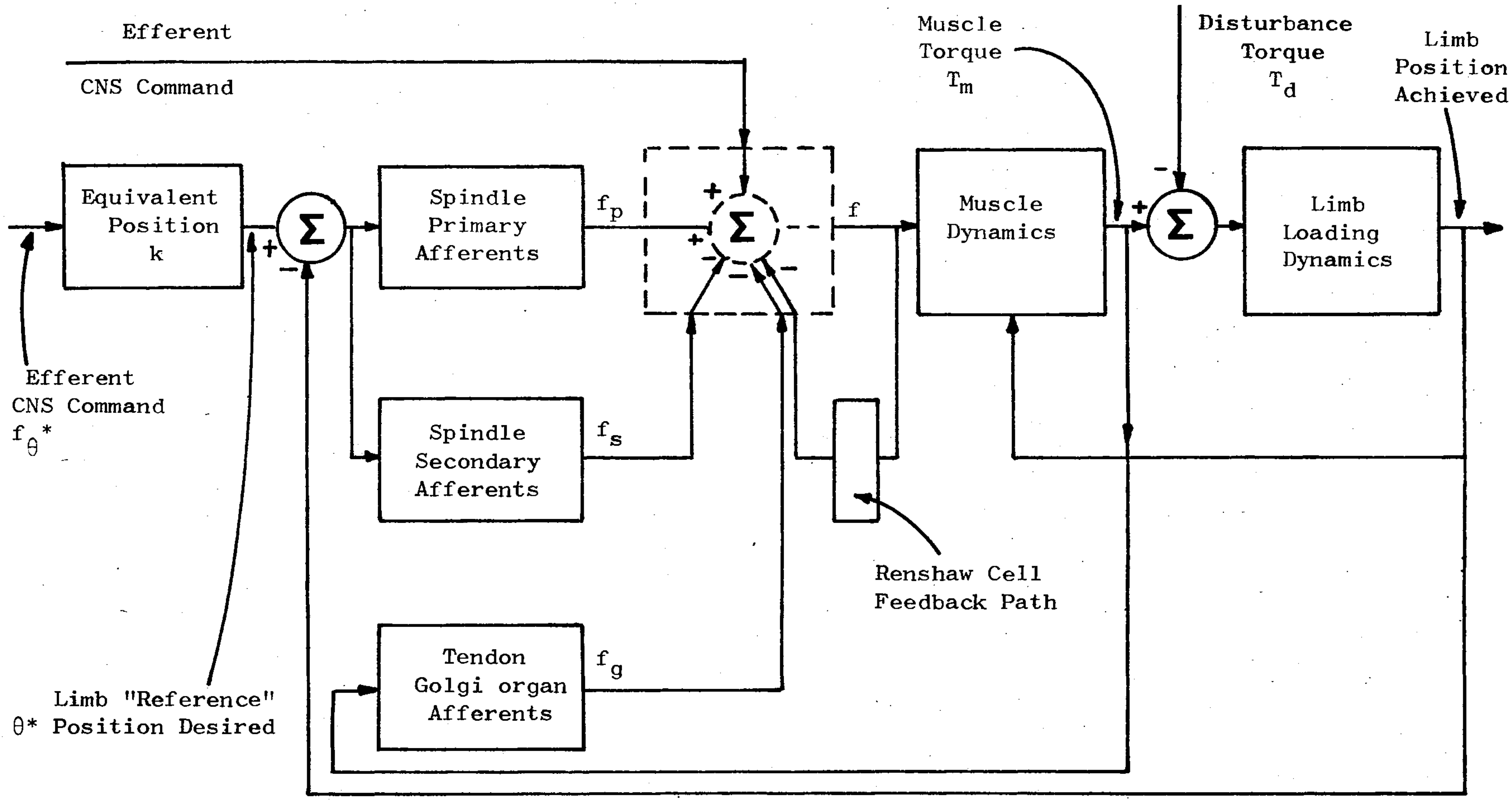
Consider the information flow diagram of the skeletal-muscle control system as shown in Figure 6.

One notes that there are two control inputs to the system. One is the r-efferent path which serves as the input when an accurate position control is required.

The other path is the α-efferent path. This path enters into the loop ahead of the spindle units, thus, is capable of fast response. This path is used for skilled tasks and for the avoidance reflex.

The control system has an overload control in the form of the Tendon Golgi Afferents. These units have a high threshold and, thus, perform the function of overload protection.

The action of the loop when viewed in block diagram form is deceptively simple. One must recall that very little is known of the dynamic responses of the various portions of the loop.



f Variables Are Pulse Frequencies

Figure 6. Block Diagram of the Skeletal Muscle Control System

The engineer's basic approach to a control system design problem traditionally has been to first determine the required transfer function, then to design a system whose transfer function is identical to the desired transfer function, and finally to implement the required transfer function.

Biological control systems present several unique problems to the engineer. The chief one is the fact that it is no simple matter to define the transfer function of a biological system. Unlike the physical systems, biological systems do not readily yield to the Bode plot or the frequency response method of generating the transfer function from experimental data.

The second major problem area concerns the manner in which the external physical system is to be interfaced with the biological system. In a biological system, one is not able to break the loop at any convenient point and insert external physical systems.

The prosthesis problem is an interesting example of the marriage between the physiologist and the engineer.

From the systems standpoint, it is an easy matter to obtain the required transfer function of the prosthesis. However, one must recall that such a determination is based upon a model that is not completely accurate.

As an example of the fact that the design of a physical system to interact with a biological system to perform a given task requires special considerations, consider the lumped parameter model of a biological control system shown in Figure 7. In this model, the inner feedback loops have been lumped into a single feedback loop.

It has further been assumed that the present transfer function up to the point of a future amputation is $G_1(S)$. The transfer function from the point of amputation to the output of the limb is $G_2(S)$. $H_1(S)$ is the feedback loop from the output of the limb to the point of amputation. $H_2(S)$ is the feedback loop from the point of amputation to the control center. The output $C(S)$ represents the performance of some desired task.

The transfer function of this system $\frac{C(S)}{r(S)}$ is given by:

$$\frac{C(S)}{r(S)} = \frac{G_1(S)G_2(S)}{1 + G_1(S)G_2(S)H_1(S)H_2(S) - G_1(S)H_1(S)} \qquad (4\text{-}1)$$

Now, assume that the limb has been amputated such that the remaining loop is as shown in Figure 8.

Now in order to perform the same function with the same dynamics the transfer function of the prosthesis and the remaining portion of the limb must be the same as given in Equation (4-1).

Assume that the prosthesis has a transfer function given by $G_3(S)$ and a feedback function given by $H_3(S)$. A block diagram of the combined prosthesis and body control system is shown in Figure 9.

For the system shown in Figure 9, the transfer function is given by:

$$\frac{C(S)}{r(S)} = \frac{G_1(S)}{1 + G_1(S)H_2(S)} \; \frac{G_3(S)}{1 + G_3(S)H_3(S)} \qquad (4\text{-}2)$$

Equation (4-2) shows that one should not try to set $G_3(S)$ equal to $G_1(S)$ and $H_3(S)$ equal to $H_2(S)$, since it is apparent from an examination

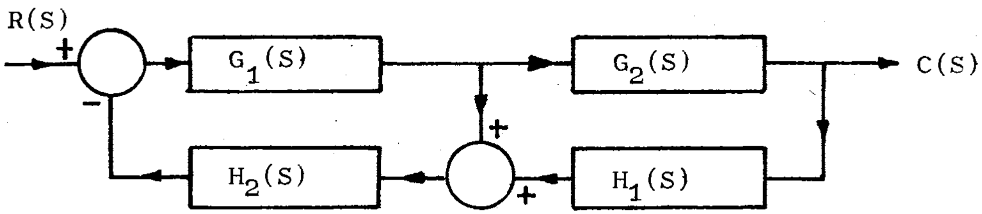


Figure 7. Lumped Parameter Biological Control System

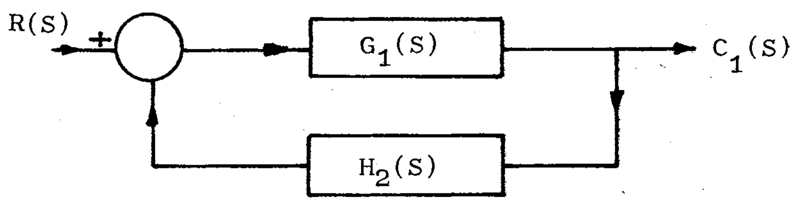


Figure 8. Lumped Parameter Limb Control System After Amputation

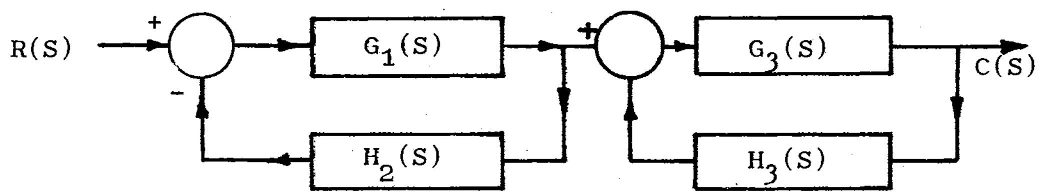


Figure 9. Lumped Parameter Limb and Prosthesis Control System

of Equations (4-2) and (4-1) that this will not make the transfer functions equal.

One possible solution is to set $G_3(S)$ equal to $G_2(S)$ then $H_3(S)$ may be expressed as:

$$H_3(S) = \frac{G_1(S)H_2(S)}{G_2(S)} \quad \frac{G_2(S)H_1(S) - 1}{1 + G_1(S)H_2(S)} \qquad (4\text{-}3)$$

Now, in order to be useful, $H_3(S)$ must be physically realizable.

Further note that due to the manner in which the feedback is inserted into the system, it is not possible to make the transfer function of the prosthesis exactly the same as the transfer function of the limb it replaces even if this process were physically realizable.

The example given above has been greatly simplified, but it does point out the difficulty of matching a biological transfer function when it is not physically possible to directly tie into the biological system.

In addition, recall that it is very difficult to devise experiments by which meaningful data concerning the dynamics of the biological system can be obtained (14).

4-2. Present Interface Systems

Most of the bio controlled prosthesis utilize electrical probes to obtain the myo-electric drive signals.

These units have the disadvantage that a conducting jelly is needed in order to reduce the resistance of the skin in the pickup area. It is an unfortunate fact of life that the conductive jellies act as a skin irritant when used over long periods of time.

Attempts have been made to implant pickup probes in the stump. These probes are used to FM modulate a carrier which is transmitted to and detected by the prosthesis and is then processed in the conventional manner.

The direct feedback to the body from the prosthesis takes the form of a tactile stimulation, an audio signal, or visual feedback. To date, these have been the only paths available for insertion of feedback information into the body.

One notes the similarity between this feedback problem in the prosthesis and the various systems which have been used to aid the blind to "see". In the latter case only the audio and the tactile paths are available for exploitation.

4-3. Bandwidth Considerations

There is evidence that many of the early models of the tactile stimulation reading devices were bandwidth limited, thus, suffering a degradation of performance (15).

Most of the early tactile stimulation reading devices contained 8 to 12 vertical sensors to sense vertical information. Experimental evidence has indicated that the bandwidth of pica type referred to the page is 75 Hertz per inch. Thus, using the sampling theorem one notes that to read pica type one requires 150 samples per inch, referred to the page.

The largest letter height encountered in pica type is 160 mills. Each photo sensor typically has a 7 mill coverage; thus, allowing for blank spaces, 24 vertical sensors are required in order not to lose vertical information.

The 24 required channels are well within the percentual capabilities of the human system.

Horizontal information is normally obtained by 6 columns of photo sensors. Recall that the page is scanned in the horizontal direction, thus, sufficient samples will be obtained with which to identify the letters.

A second experiment related to bandwidth considerations are performed by Taenzer (16).

His experiment utilized a computer controlled neon bulb array. His letter size was 12 vertical columns high and 8 columns wide.

He determined that at a reading rate of 24 words per minute and at 60 words per minute that a display time of 150 milliseconds was required for a person to correctly identify a letter 95 per cent of the time.

This data was obtained with a window width of 6 columns.

He also performed experiments concerning reading rate, accuracy, and window width. As was expected, whenever the window width approached the letter width the person began to read at his normal rate. Recall that this reading is accomplished one letter at a time, thus, not making use of the parallel entry capabilities of the visual system.

Extrapolating Taenzer's results, one notes that a display time of 150 milliseconds gives rise to a reading rate of 400 letters per minute. This rate is based upon a single letter window width. Thus, one notes that in the case of a sighted person reading text in which one letter is exposed at a time his speed would approach 80 words per minute, assuming an average of 5 letters per word.

The above does not account for the time spent in scanning and in correction of the alignment of the scanning window whenever one makes a change in lines.

Taenzer (16) also determined that the tactile stimulation devices also required 150 millisecond exposure time in order for the subject to identify a letter.

Thus, it would appear that neglecting scanning time the upper limit to the reading rate of the single letter devices would be approximately 80 words per minute.

The engineer normally expresses bandwidth in Hertz and not referred to as a page of print. When one considers Taenzer's results, he notes that a single letter requires 150 milliseconds of display time. Bliss (15) has noted that pica type requires 24 samples in order to correctly identify the given letter. The number of samples per second required is 160. One then concludes that the bandwidth of the system used in single letter heading is 80 Hertz.

Collins (17) has suggested that the input capacity of the skin on a man's back is 4m Hertz. His calculations were based on 4000mm^2 of skin on the back. Each tactile stimulator required $.4\text{mm}^2$. This gives a maximum rate of 400 Hertz, thus, he obtains 4m Hertz as the input capacity of the skin.

One should not confuse the term input capacity with bandwidth. An analogy to the situation would be the case where one has 10,000 ideal low pass filters whose cutoff frequencies are 400 Hertz. Thus, if one connects them in parallel, he may pass 10,000 signals each one having a maximum frequency of 400 Hertz. The bandwidth of the system from an engineering standpoint is still 400 Hertz. However, since the filters are independent one may process 10,000 different signals. The input capacity is obtained by multiplying the number of independent channels available times the cutoff frequency of the channels. In this case all of the channels have the same cutoff frequency eliminating the need for channel-by-channel summation.

4-4. Experimental Reading Rates

Troxel (18) in a series of experiments concerning the reading rate via the visual and tactile reading channel experimentally determined that the reading rate whenever letters were exposed one letter at a time was approximately 20 words per minute.

In this experiment, the visual rate was determined by using a computer controlled device that exposed the letters one at a time upon command of the subject.

The tactile reading rate was approximately the same as the visual reading rate. Troxel concluded that the rate was channel limited rather than comprehension limited.

J. C. Bliss (20) has obtained results that disagree with those obtained by Troxel although with the same size of samples used disagreements are certain to occur. He has obtained tactile reading rates at 60 words per minute.

4-5. Experimental Reading Rates - Discussion of the Experiment

No experimental data was found in the literature concerning the reading rate of individuals when they were required to read a text with a device that allowed them to scan and observe only one letter at a time. This is essentially the case in tactile stimulators.

This seems to be a good method for obtaining the necessary feel as to how good the progress in tactile stimulator reading devices has been.

It seems more logical to require the individual to do his own scanning rather than having the computer perform this function. Since in the final analysis, the blind individual must be able to scan the page at his own rate.

Thus, the following experiment was devised. Five subjects were chosen. These subjects were required to read an article from a magazine or paper that they had not previously read. They were given a cardboard scanner which had a single slit in it. They were told to read the article aloud as they scan it one letter at a time. Their reading was recorded and later compared to the printed text. If at least 95 per cent of the words were correct, no special notation was made on the data.

The data is presented in tabular form and compared to the results obtained from the tactile devices.

4-6. Experimental Results

The subjects were required to read aloud passages from a magazine which they had not previously read. The length of the reading period was 5 minutes. At the end of 5 minutes the subjects were given the signal to stop and the total number of letters they had read were tabulated.

The subjects' reading rate was computed by taking the total number of letters they had read and dividing them by 5. In this case 5 letters has been assumed to be the length of the average word.

The subjects were required to perform this task on five consecutive days. After an initial adjustment period, very little difference was noted in their reading rates as a function of time.

Subjects A, B, and C were college graduates. Subject D is a Junior in college.

Subject E is an eight year old boy. He, of course, was not required to read the same magazine that the other subjects.

The average reading rates obtained by these subjects is given in Table I.

TABLE I

AVERAGE READING RATES OF THE SUBJECTS

Subject	Average Reading Rate
A	36 wpm
B	35 wpm
C	32 wpm
D	25 wpm
E	22 wpm

One notes that this data lies between that obtained by Troxel (18) (20 wpm) and that obtained by Bliss (20) (60 wpm).

Each of the subjects complained of being nervous as a result of reading in this manner. The reading rate was so slow that it made them uncomfortable.

4-7. Experimental Conclusions

The data obtained in Section 4-5 when considered in light of Bliss's (20) data suggests that the people who are able to read at a rate of 20 wpm with the tactile reading devices are performing rather well. Those who read at a rate of 60 wpm are reading at a remarkable rate.

It further suggests that this type of reading will be rather uncomfortable and that the subject will need a training period to become acclimated to this slow rate of reading.

Note that in this particular experiment no graticules were used; thus, the full bandwidth of the type was transmitted to the subject. In order to evaluate the effects of limiting the bandwidth, graticules would have to be devised that would expose samples of the letter rather than the full letter to the subject. It was noted that whenever the subject lost scan synchronism, i.e., slipped to the wrong line, very little time was required for him to get back on target.

It might be argued that requiring the subject to read aloud may have slowed him down. However, when evaluating their speaking rate on a subjective basis it seemed that the reading rate was the dominant factor rather than the speaking rate.

CHAPTER V

ELECTRONIC AND ELECTROMECHANICAL AIDS FOR THE TRAINING OF THE MENTALLY HANDICAPPED

5-1. Teaching Machines

In early 1966, the outlook for electronic teaching aids for general use was very promising. Market researches had indicated that this would be fruitful and various companies were standing in the wings waiting to market their particular product (18).

However, in 1969, it became apparent that too many of the devices have been designed for a particular task with no real communication between the engineer and the educator. Too many of the products were too costly, not reliable, and contained many defects that could have been avoided if a closer contact had been maintained between the educator and the engineer (19).

The basic thrust in the area was in that of manufacturing teaching machines. These devices were, in general, of such a nature that they allowed the student to proceed at his own rate and provided instant feedback in case that the student had made an error or failed to grasp a particular point.

In general, most of the teaching machines used the process of multiple choice in testing the student. Many educators diagreed with this type of testing and felt that the student should have an option of inserting his own answer (18).

In response to this request, Valdimer Stephan, of Prague, Czechoslovakia, designed a teaching machine that allowed the student to make a free choice of his answer. The machine was still capable of grading the student's response and would indicate to him whether he should proceed with the lesson or be given a review lesson.

The basic idea of the teaching machine seemed to be to relieve the teacher of the necessity for pacing his class in response to the abilities of pupils that he may have enrolled in that class. The machine, in principle, would let each student proceed at his own pace, provide testing, and make data available to the teacher as to the progress of a particular pupil.

The teaching machines appear to have two basic problems. The first is that the machine that is truly adaptive will normally be connected to or be an integral part of some type of computer. Thus, the cost of the device becomes a barrier to its widespread use.

The second is that the machine which does not make use of a computer becomes much less flexible and requires changes in its program to adapt to its various classes. Thus, it seems that there is a direct trade off between utility and price.

5-2. Use in the Training of the Retardees

The retardee presents very special requirements to the educator. He is in need of training that is of a highly repetitious monotonous type. He requires immediate feedback and a great deal of guidance in the accomplishment of a given task.

It would seem, that since a good deal of the training of the retardee is of a one-to-one nature, this would be a case where teaching machines would be extremely useful. Blackman and Capobianca (20) have indicated that teaching machines should do a very good job in teaching retardees.

The teaching machine is characteristic of an immediate response to the correctness of an answer or a task is particular suited to the retardee's needs.

Teaching machines become especially useful from the standpoint that a retardee is at a particular disadvantage in a classroom, even though the classroom is specially designed for the retardee. The retardee has very little chance of correctly performing a given task. Thus, has little chance of gaining a personal reward. The teaching machine would be especially useful in the home environment.

However, again one is reminded of the cold hard fact of reality that teaching machines are too expensive to become a part of each retarded child's home. The cost of teaching machines are such that even the state institutions have trouble obtaining the teaching machines. When they do obtain them, they are not in sufficient quantity to allow the students to have full access to them.

5-3. Devices Other Than Teaching Machines

Tape recorders, video recorders, and other special purpose audio equipment have been used in the training of retarded children. These include the language master and talking typewriter as devices that appeal to the audio as well as the visual information channel.

It should be pointed out that a good deal of the training is individualized and requires a great deal of effort on the part of the teacher to tailor the subject to fit a particular student's need.

No simple electronic devices are available which could be used to develop the basic visual muscular coordination skills of the retardees. An outline of the various programs used in the training of retardees is found in Loves' book on the teaching of the mentally retarded (21).

5-4. Future Needs

It seems that the training of retardees would be particularly suited to the use of electronic feedback devices, but very little effort has been expended in the area of low cost, safe, and reliable devices. This could be due to a lack of knowledge of the nature of the problem or due to the fact that market researches have indicated that such devices are not economically feasible. It appears that there exists a real need for the engineer to design cheap, reliable training aids for the teaching of basic skills to the mentally retarded.

CHAPTER VI

THE AUDIOGRAPH

6.1. Background Information

The area of electronic and electromechanical aids for the mentally retarded has a special appeal for the author. First, the results of the literature survey indicated that very little has been done in the development of training aids in this area except in the realm of teaching machines, tape recorders, and talking typewriters which are reliable but not cheap.

Secondly, the author has developed many contacts over the past ten years with workers who were concerned with the training of the mentally retarded. These contacts were willing to furnish guidance in their own particular specialty and were willing to supply subjects for the evaluation of the devices.

Blackman and Capobianca (20) have indicated that teaching machines should do a very good job in the training of retardees. The fact that the machines upply an immediate indication of the correctness or incorrectness of a student's answer or his performance of a given task is particularly suited to the needs of the retardee. They felt that the teaching machine would be especially useful in the home environment. However, once again, the cost of the machine mitigates against this use of the machine.

On the spot observations and conversations with the teachers of the retardees indicated that the general area of the development of eye-muscular coordination was a prime candidate for an electronic teaching aid. The development of the eye-muscular coordination is necessary in order that the students may learn to write. Quite often the student is fully aware of the shape of a particular letter or a geometric figure but he is unable to effectively control his fingers, hand, and arm. Typically, the student is given intensive training in order to prepare him to write. This training is of a boring repetitious nature. The student traces over a particular figure and letter until he develops the mental and eye muscular coordination patterns by which he can print on his own. The teacher must closely supervise this task since in many cases the retardee is perfectly happy not following the outlined figure or letter.

In particular, a student was observed who had been trying to learn to print his name for a long period of time. He was having extreme difficulty in mastering the task and had become so bored that he had decided to quit trying. It was at this point that the basic idea for the audiograph was born.

The audiograph fits into the general category of devices which are keyed to visual and audio stimuli. An extensive review of the literature indicated that the audiograph approach was unique. A patent search conducted in December 1970, indicated that there was at that time, no devices under patent that duplicated or even approached the proposed applications of the audiograph. Further evidence that the audiograph was unique was obtained from conversations with the administrators and teachers of various training centers for the mentally handicapped.

It has been argued, Ames (22), that perceptual performance and development are closely related, and that many of the tests which measure developmental level depend upon perceptual functioning which, in turn, depends upon how far the child has developed.

The audiograph leans heavily upon the audio stimulus; thus, it is reasonable to inquire as to whether or not the children it would be used on would be able to hear the tone. A recent experiment by Doehring and Rabinovitch (23) led them to conclude that children with learning disabilities were within normal limits in thresholds for pure tones and speech. This conclusion is in agreement with conversations this writer has had with the teachers in this field in which it was stated that the music center of the brain is one of the last places to be damaged in the case of brain damage.

Initially, the scope of the device was very broad; the first scheme consisted of a system such that the child was made aware of his position on the writing pad by means of an audio signal whose frequency varied as a function of the position of the stylus upon the writing surface. Vertical information was sensed by a change in frequency. Horizontal motion was sensed by a warble tone in addition to the change in frequency. The warble tone was necessary since at least two positions on the given surface were at the same potential, which meant that they would cause the oscillator to produce a signal of the same frequency.

The heart of this system was a voltage controlled Wein bridge oscillator. The variable resistive elements were diodes whose resistances were changed by varying the bias on the diodes.

Teledeltos resistance paper was used as the element with which to vary the voltage as a function of position. Fixed voltages were applied to the edges of the teledeltos paper, thus making any two symmetrically opposed points on the paper assume a particular voltage level.

This initial audiograph had several features that made it less than ideal. The first objection was that it was difficult and relatively expensive to construct. The cost was approximately $100, thus violating one of the initial assumptions of this thesis.

Secondly, the writing surface was of teledeltos paper, with the appropriate pattern inscribed, and this had a tendency to wear out under hard usage.

Primary power was supplied to the unit from the 110-volt line. Safety considerations dictated the use of dry cell batteries as the primary power source rather than the AC line.

The last and most profitable observation on this unit was that the children did not seem to be too interested in the change in pitch, but rather were listening for the presence or absence of the tone.

It was then apparent that the initial unit was too sophisticated and that the proposed application for the unit could be satisfied with a simpler scheme.

6-2. The Audiograph

After numerous trial and error sessions, the audiograph evolved to its final configuration which consists of a simple relaxation oscillator, a converted clipboard which is used as the writing surface, a probe or stylus, interchangeable training templates, and either a loud speaker or an earphone. The units are powered with two conventional 1.5 volt D cells, thus reducing to nill the possibility of an electrical shock. See Figures 10 and 11.

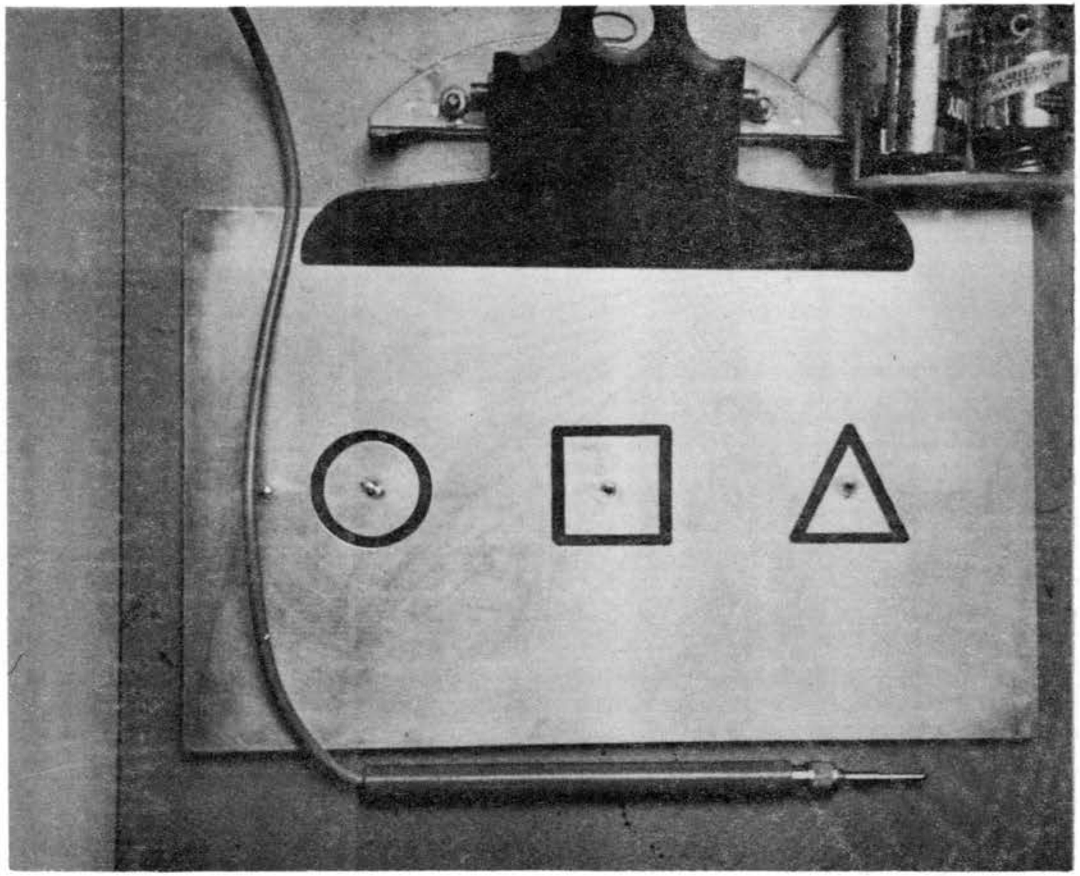


Figure 10. Picture of the Audiograph

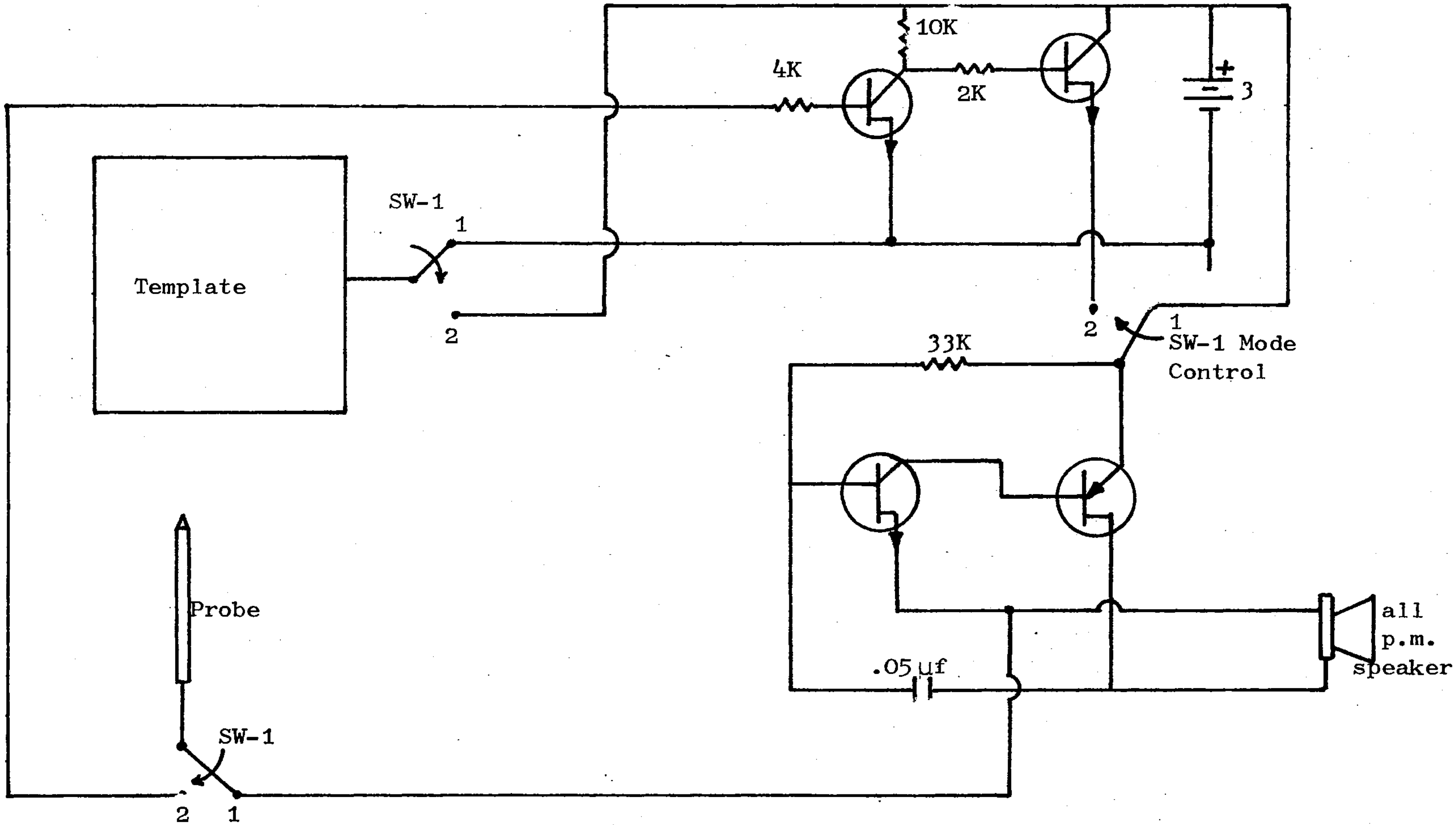


Figure 11. Schematic Diagram of the Audiograph

The audiograph functions in one of three modes depending upon the nature of the task and the template.

If the mode selector switch is in position one and the pattern that the student is required to trace on the template is of insulating material, the audiograph functions as an error detector and will give a stimulus consisting of an audio tone whenever the student makes an error. An error here is interpreted to mean that the student has strayed from the confines of the desired pattern. When the student strays from the desired pattern, the audio oscillator is activated and the student is given an audio tone.

In the second mode of operation, the base of the transistor switch is forward biased and the audio oscillator will not be activated as long as the stylus is in contact with the prescribed pattern. See Figure 11. In this second mode of operation, the desired pattern is made of conducting material surrounded by an insulator. This mode is particularly useful when one is engaged in a timed test or task such as tracing mazes.

Operation in mode three functions in the reverse of mode one by using a template with the pattern inscribed on conducting material. In this mode, the student is given an audio tone as long as the stylus is in contact with the prescribed pattern. An error in mode three is detected by the absence of the audio tone.

The present templates consist of conventional copper clad printed circuit boards. If the template is to be used for operation in mode number one, the desired pattern is etched into the copper. This gives rise to a copper pattern surrounded by fiberglass. The templates are easily changed. This is accomplished by raising the spring loaded clip on the clipboard, removing the old template, and inserting the new one.

The probe consists of a conventional voltmeter probe and a flexible wire. The probe is shaped such that it does not have a sharp enough point to be considered as a hazard to the operator. The electronic portion of the unit is housed in a minibox. For ease of replacing the batteries, they are mounted in a battery clip on the outside of the minibox. The total cost of the components of the unit, including a loud speaker but not the earphone, is in the neighborhood of five dollars.

The construction of the units requires no particular skill except that of drilling and soldering. The units are reliable. The skill used in constructing the units is visible only as an external effect. The basic unit will function even with the most crude attempts at fabrication.

6-3. Functional Description of the Audiograph

A block diagram of the audiograph is shown in Figure 12. The operation of the unit is as follows:

A. When Used in Mode Number 1

The mode selector switch is in position number 1 which removes the transistor switch from the circuit. The template used in this mode has the desired pattern inscribed on an insulator surrounded by a conductor. The negative side of the three volt power supply is connected to the spring loaded clip on the clip board. Contact to the template is made through this spring loaded clip. The student traces the pattern on the template and, if he remains within the prescribed limits, power

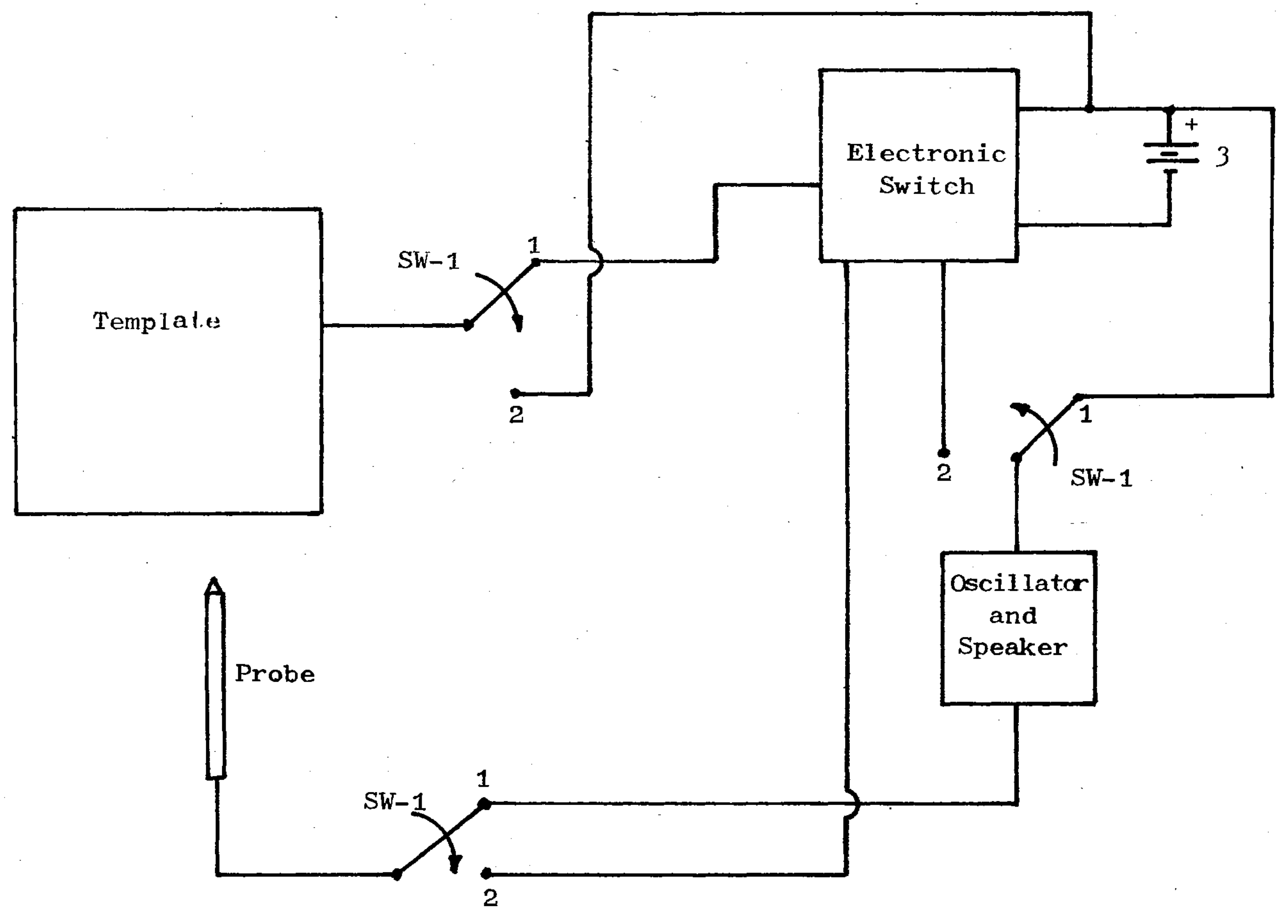


Figure 12. Block Diagram of the Audiograph

to the audio oscillator is cut off and he will not receive an audio tone. If the student strays from the prescribed pattern, the probe touches the conducting portion of the template completing the path for the power supply through the probe to the audio oscillator thus the student receives an audio tone.

B. When Used in Mode Number 2

The mode selector switch is placed in position number 2. The transistor switch is closed.

Power is supplied to the audio oscillator whenever the probe is not in contact with the prescribed pattern. The template used in mode 2 has the desired pattern inscribed in copper surrounded by an insulator.

The student will receive an audio tone as long as he is off target. The audio tone will cease whenever the student is on the prescribed pattern. When the probe is in contact with the target, the transistor switch opens removing the power to the audio oscillator.

This mode is especially useful when requiring students to trace mazes or to eliminate any attempts to speed up progress by moving the stylus from the beginning to the end without contacting the pattern.

C. Operation in mode 3 is accomplished by placing the selector switch in position number 1. This removes the transistor switch from the circuit. In mode 3 the template is the same as that used in mode number 2. However, in this mode the student is given an audio tone only if he remains on target. The probe contacts the conducting material of the desired pattern completing the circuit from the positive side of the power supply to the audio oscillator. This circuit is broken if the student strays from the confines of the desired pattern.

6-4. Eye-muscular Coordination Game

The initial users of the Audiograph indicated that it served to motivate the students to engage in eye-muscle coordination exercises. Further investigation revealed that the addition of a spiral wound wire and a loop to the basic Audiograph provided another eye-muscular coordination exercise with little or no increase in the cost of the basic unit.

The spiral wound wire is so constructed such that it plugs into a banana plug on the Audiograph unit. The metallic loop and the spiral wound wire act as a switching device which activates the oscillator whenever the wire and loop come in contact with each other. See Figures 13 and 14.

The object of the game is for the student to thread the metallic loop around the spiral wound wire without touching the loop to the wire. Thus, the student may practice 3-D eye-muscular coordination exercises with the assurance of immediate detection if he makes an error. This portion of the Audiograph is similar to the game of pick-up sticks in its eye-muscular coordination requirements except in this case there is an impartial referee who makes an immediate decision in case of an error.

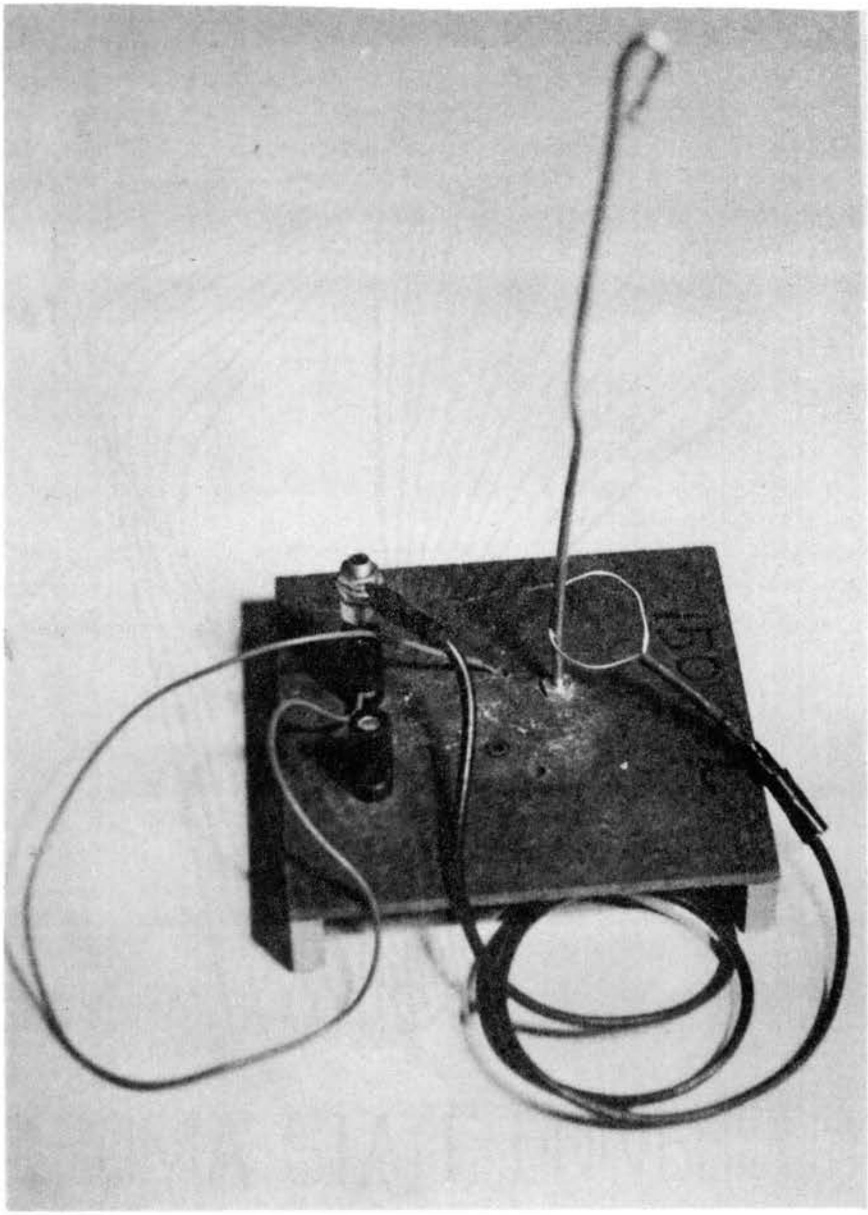


Figure 13. Picture of the Eye-Coordination Game

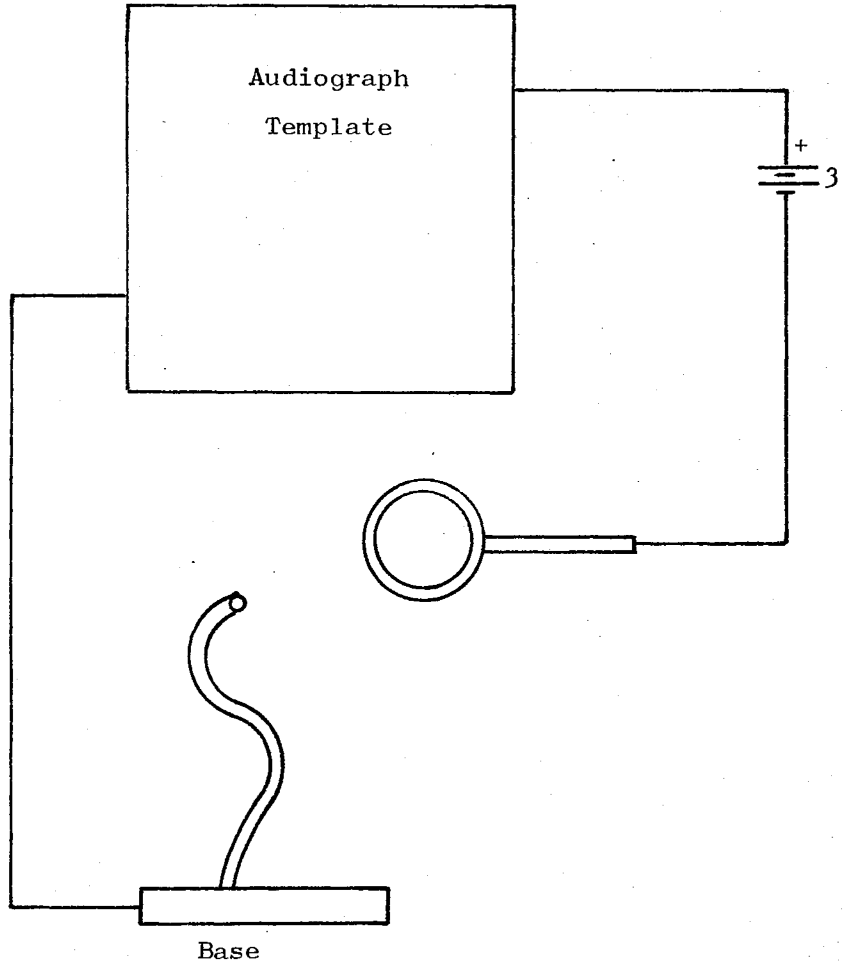


Figure 14. Block Diagram of the Eye Coordination Game

CHAPTER VII

EXPERIMENTAL RESULTS

7-1. The Audiograph Experiment

In cooperation with the Starky Developmental Center at Wichita, Kansas, six students were chosen to participate in this experiment. The following experiment was devised to aid in the evaluation of the Audiograph.

The subjects were given the task of learning to draw and identify basic geometric shapes consisting of the square, circle, and the triangle. The subjects were so selected that the task of learning to draw and name the basic geometric figures presented a real challenge to them.

The subjects were divided into three groups and approached the task in accordance with the following group assignments:

> Group #1 practiced tracing the figures on the Audiograph and were given an audio stimulus whenever they made an error. Group #2 practiced tracing the figures on the Audiograph, but were not given the audio stimulus whenever they made an error. Group #3 practiced tracing the figures on a dittoed sheet and were, of course, not given the audio stimulus.

The length of the task was governed by the instructor. She halted the training of a particular subject whenever she felt they had mastered the task. The instructor was also given the prerogative of changing subjects from the ditto and no audio groups to the audio group if she felt that the audio tone would aid the subject. Such cases are noted in the data section of this chapter.

The evaluation sheet used in this experiment required that the subject trace the figures prior to and after the training session. The first tracing was to note the day-by-day retention of the subject and the second tracing served to evaluate the results of a particular training session. The instructor entered comments in the evaluation sheet concerning the actions of a particular subject and his apparent motivation. The subjects were given the training and evaluated at least twice a week.

7-2. The Subjects

The subjects used in this experiment were given coded identities and will be referred to in this thesis by a code name rather than by their given name.

The groups referred to in section 7-1 consisted of two students each. The composition of the groups were as follows:

Group #1: Subjects 1-A and 1-B were brain damaged children with poor coordination. Subject 1-B is unable to prevent her hands from shaking.

Group #2: Subject 2-A is a brain damaged child. He has coordination problems but his coordination is superior to that of the other subjects used in this experiment. Subject 2-A is also judged to have more learning potential than the other subjects utilized in this experiment. Subject 2-B is a child with cerebral palsy and has poor coordination.

Group #3: Subject 3-A is a brain damaged child with poor coordination. Subject 3-B is a brain damaged child with poor coordination and limited speech ability.

7-3. The Evaluation Sheet

A copy of the evaluation sheet is shown in Figure 15. The nominal time of each training session was from 5 to 10 minutes. This time varied since all subjects were given their conventional training while simultaneously participating in this experiment. The order of the geometric figures was varied on the sheet in order that the student would not associate a particular figure with a given space.

Each of the subjects were required to trace the geometric figures prior to and at the end of each training session. The answers were recorded by the teacher. In case the student named a geometric figure other than a square, circle, or a rectangle, this answer was noted by the teacher.

In the case of subjects with limited speech capability, the teacher would have the subject point to the geometric figure that the teacher named. The reverse side of the evaluation sheet was reserved for comments by the teacher. These include comments on the nature of the subject's progress, his attitude that particular session and his apparent motivation.

Any variations from the experimental procedure were noted in the comments section. For example in the case of subject 2-B, the subject was very reluctant to practice without the benefit of the audio tone; thus, he soon learned to activate the tone and if left to himself would do so during the training session.

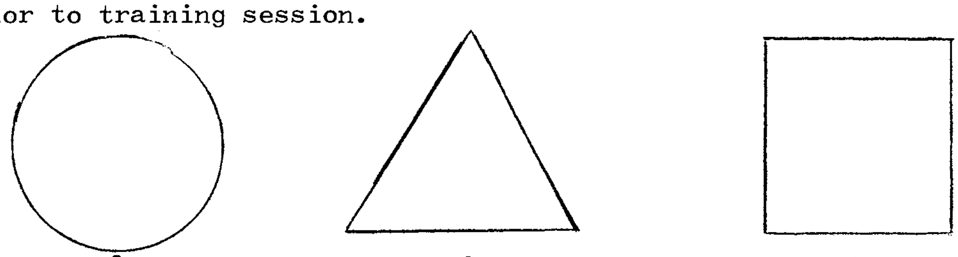
DATE ____________ STUDENT NO. ______ AUDIO TONE USED YES ___ NO __

DITTO USED YES ___ NO ___

Approximate training time this session ______________

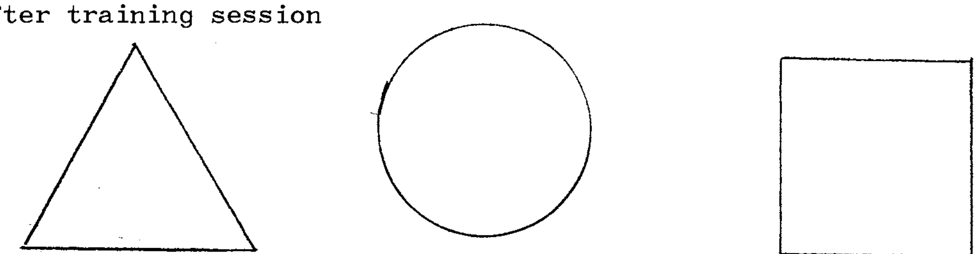
Have the student trace the figures shown below.

Prior to training session.



3 2 1

After training session



2 3 1

Students Answers
Check One

1.	2.	3.
Square ____	Circle ___	Triangle ____
Circle ____	Square ___	Circle ____
Triangle ___	Triangle ___	Square ____

Teachers comments on reverse side.

Figure 15. The Evaluation Sheet

7-4. Method of Scoring

The data was scored in the following manner. The tracing made prior to and after the training session will be scored by means of a template (Figure 16). The template consists of the basic geometric figure and several superimposed figures. The sizes of the superimposed figures are related to the basic figure by integral multiples of 1/16 inch.

The template will be matched to the reference figure on the data sheet. The tracing will be scored in the following manner. If the subject's tracing is within 1/16 inch of the nominal size of the reference figure, he will be given a zero. If it is between 1/16 inch and 1/8 inch of the nominal size of the reference figure, he will be given a one. The remainder of the scale is scored in a similar fashion; i.e., if the subject's tracing is between n/16 inch and n+1/16 inch of the nominal size of the reference figure, he will be given a score of n.

Each side of a particular figure will be scored. In the case of the circle, 90 degree segments will be used. The score, thus, will reflect the magnitude of the maximum distance that the student strayed from a given side of the reference figure as he attempted to trace the reference figure.

The total score of the subject as pertains to a given geometric figure will be computed by summing the scores that the subject obtained on the particular segments of that geometric figure.

The freehand sketch was not scored using the above procedure, but a copy of the subject's sketches during the first training session, the middle of the training sessions, and the last training session will be presented in the section 7-5.

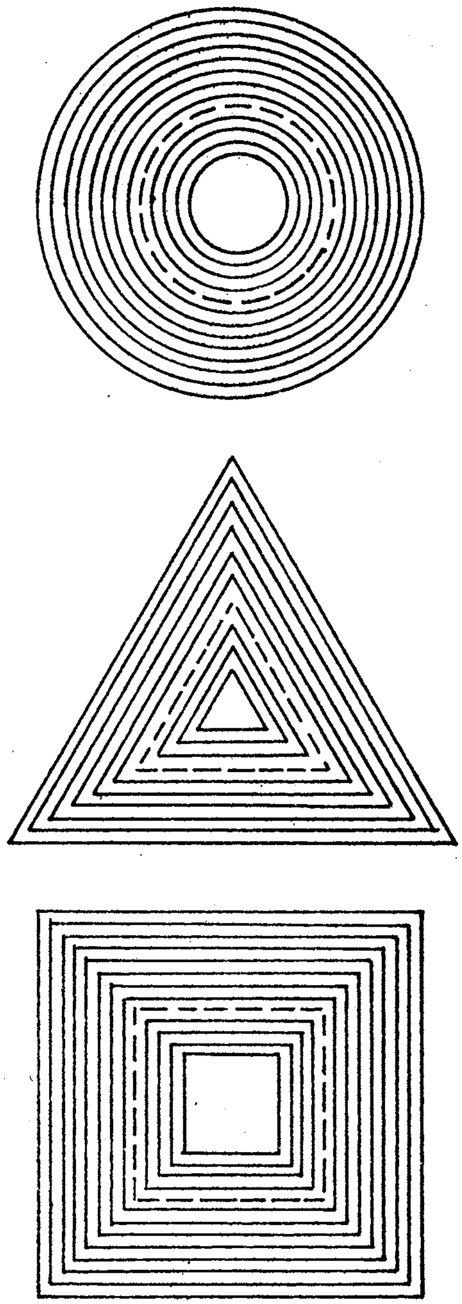


Figure 16. Scoring
Templates

7-5. Results of the Audiograph Experiment

The subjects' scores on the tracings are presented in Figure 17 through Figure 38. In each case, a straight line has been passed through adjacent points of the data. The figures are arranged in ascending orders of subjects. In some cases the subject did not trace the figure such that it could be scored. In these cases, no data is presented. If there is a deviation from the experimental procedure, it is noted on the score sheets.

One notes that, in general, the circle presented the most difficult task to the subjects. Arcs proved more difficult for the student to trace than the straight lines of the square and triangle.

The nature of the data is such that a subject-by-subject presentation is warranted.

Subject 1-A is a brain damaged child with poor coordination. Subject 1-A already knew the names of the figures, but had great difficulty in attempting to trace or sketch them. This subject's results are shown in Figures 17 through 20.

In the case of the circle, one notes a marked improvement in his performance after the first two training sessions. He continued to improve up to the twelfth training session at which time his score began to oscillate around a value of 4. His performance on the tracing of the square and triangle shows similar results. The instructor terminated the training sessions for this subject at number 18.

The initial attempt of Subject 1-A to sketch the figures is shown in Figure 20. One notes that the size of the figures are considerably larger than the reference figure. His triangle and circle are fairly good; however, his square has three sides instead of four. This

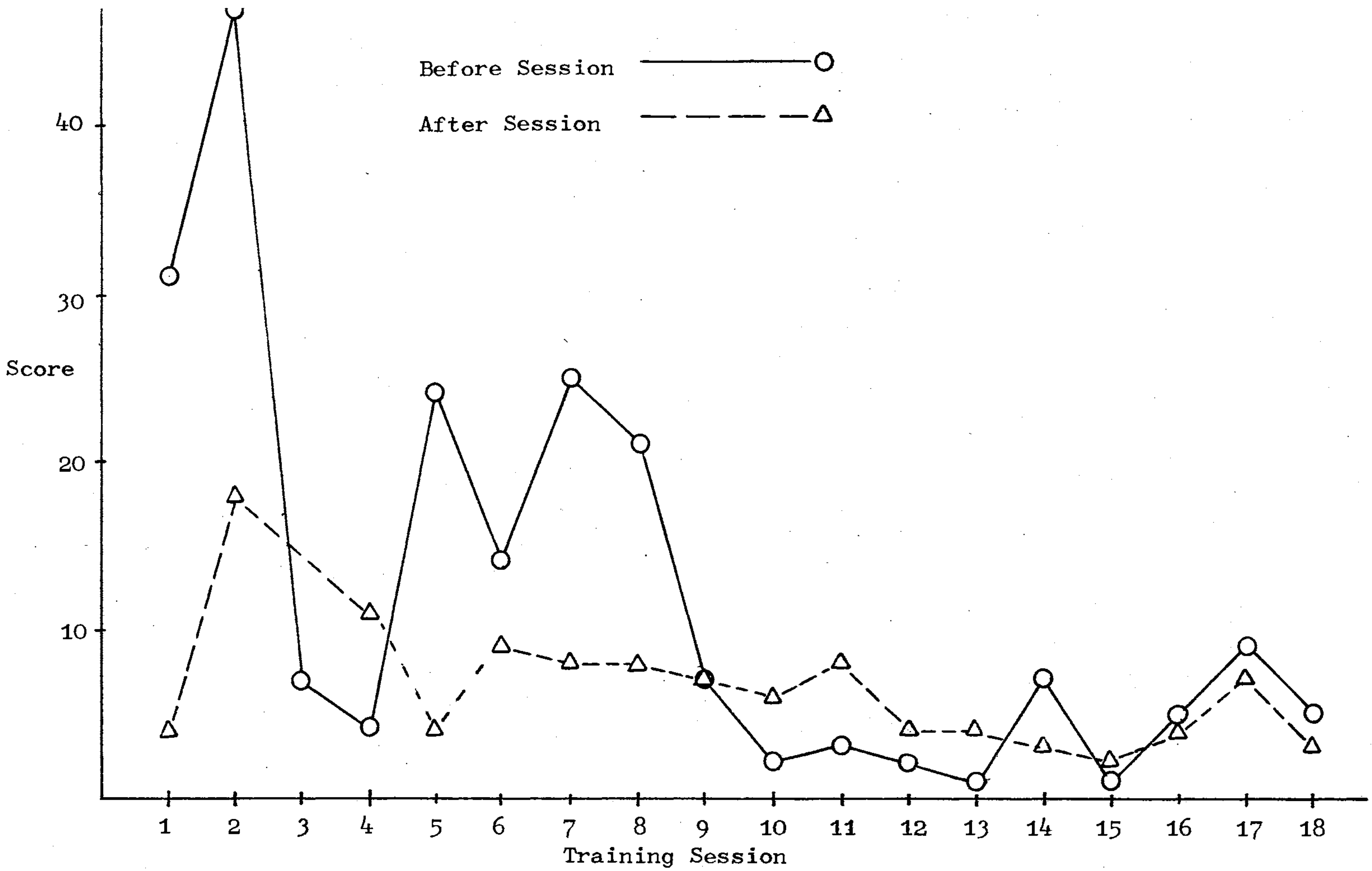


Figure 17. Subject 1-A Circle Tracing

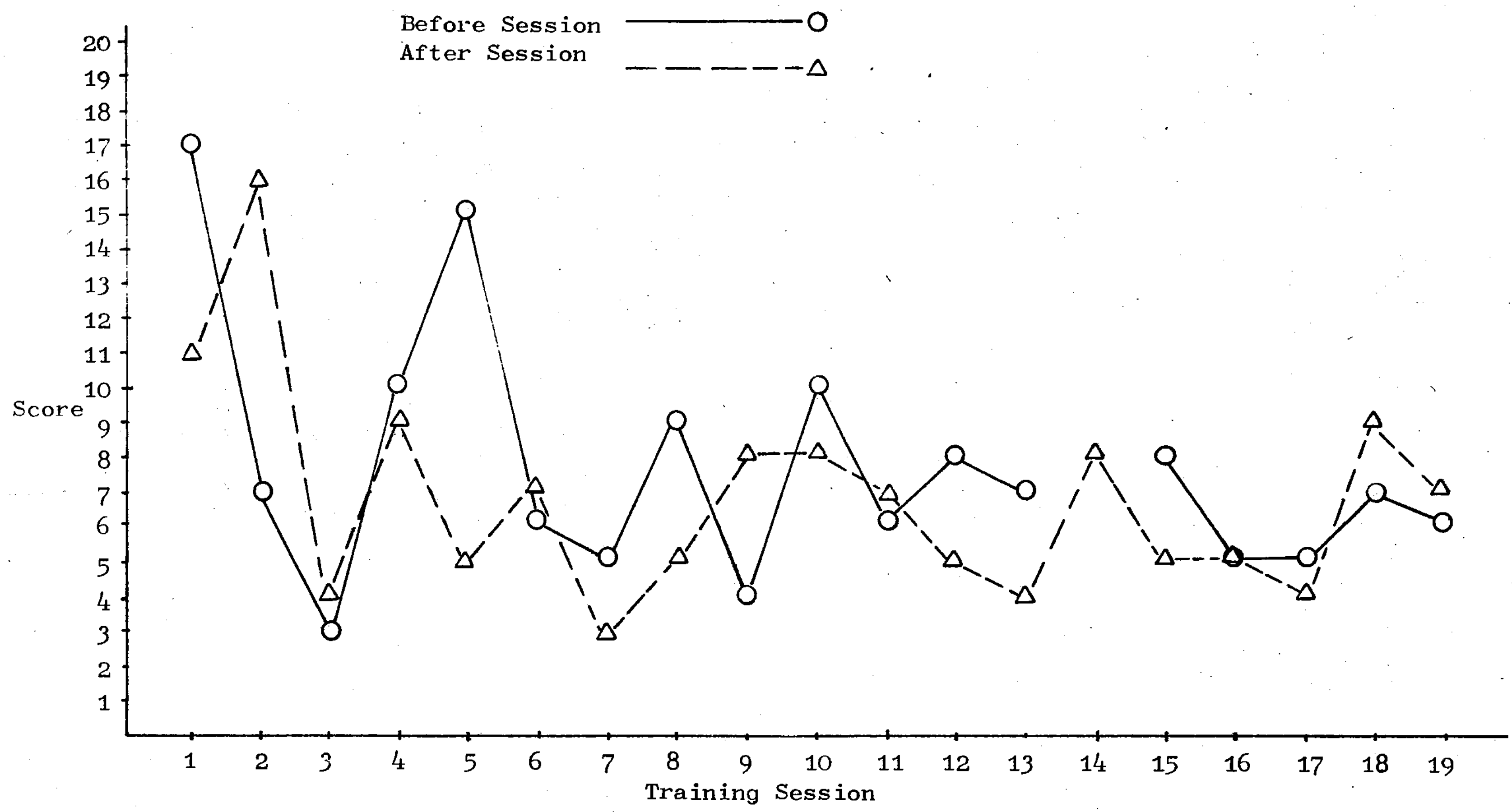


Figure 18. Subject 1-A Square Tracing

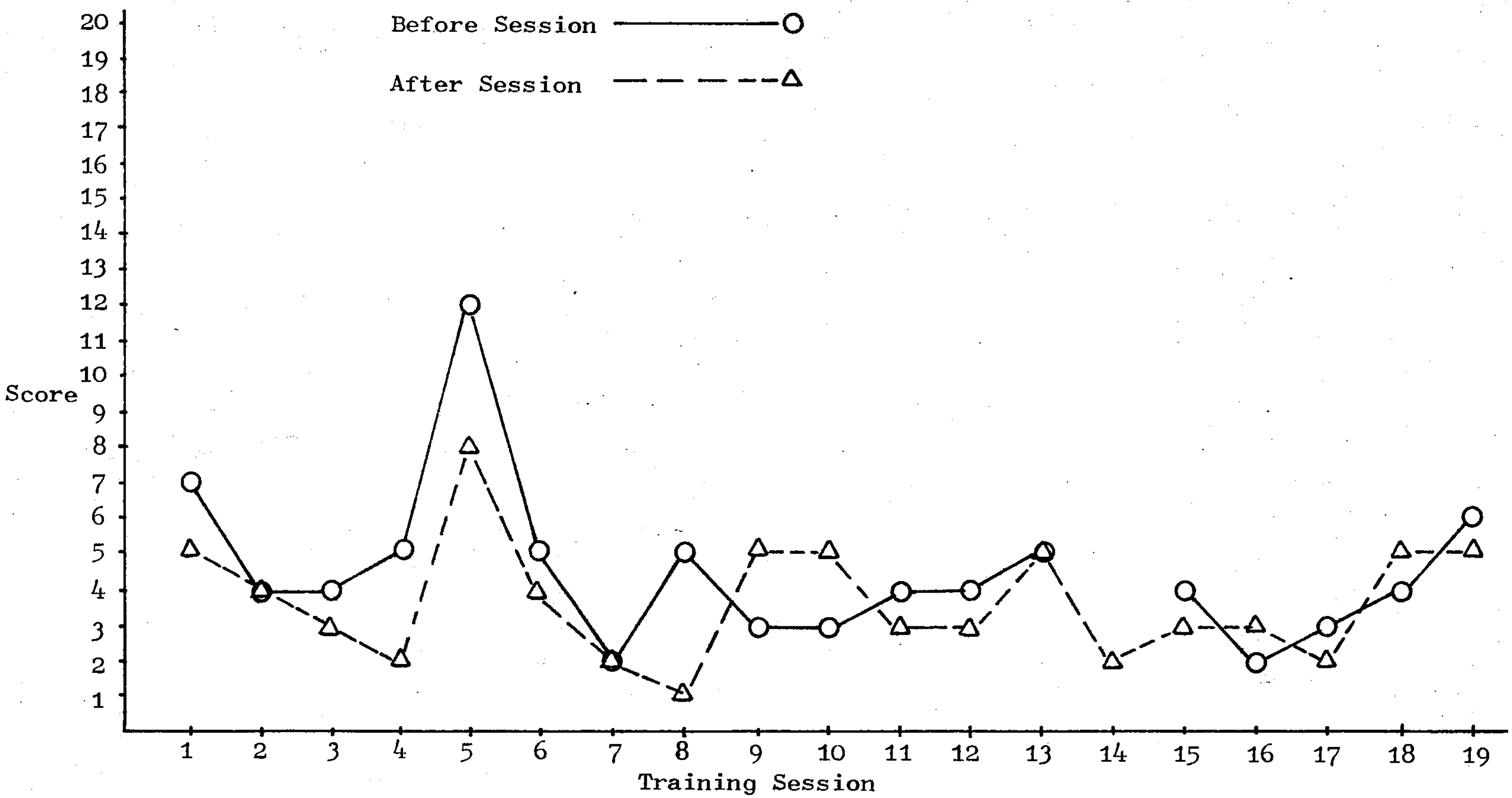


Figure 19. Subject 1-A Triangle Tracing

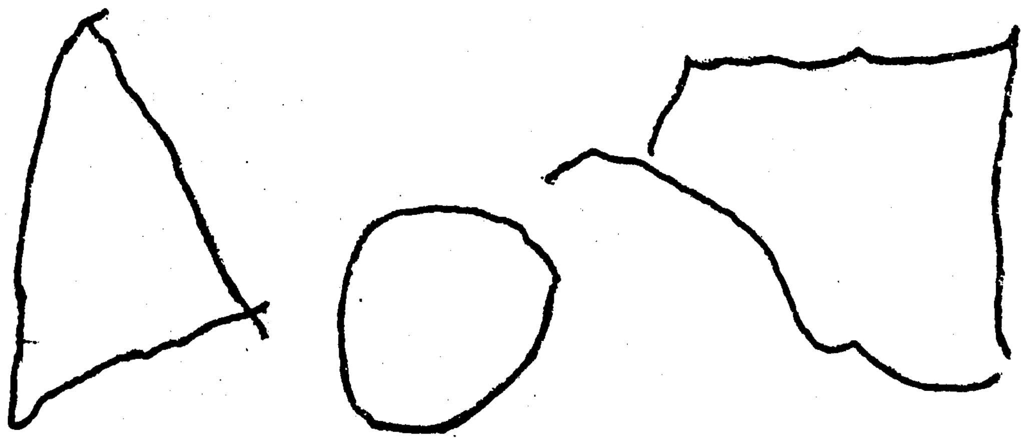


Figure 20. Subject 1-A Sketches After Session 1

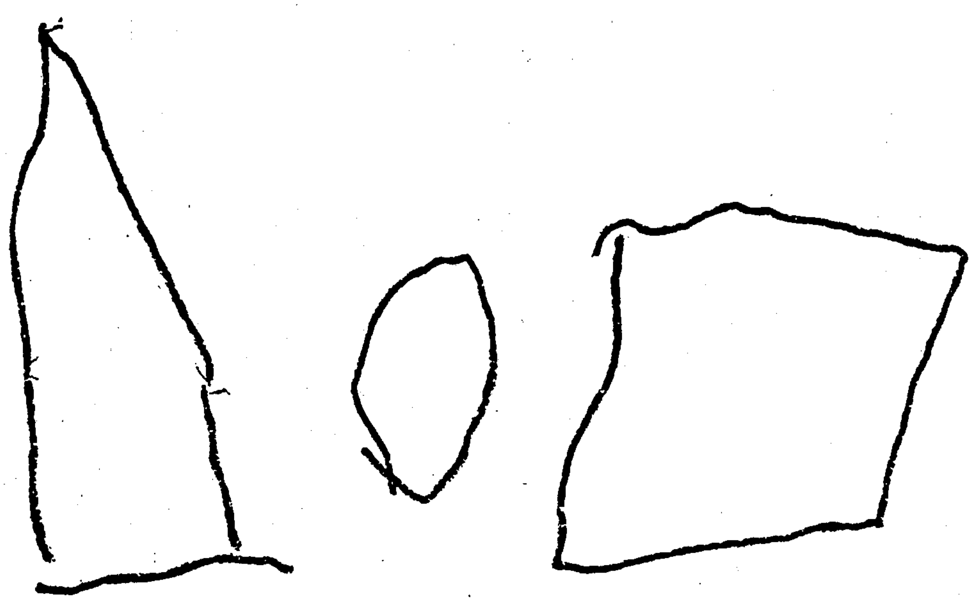


Figure 21. Subject 1-A Sketches After Session 9

subject's nineth sketch (Figure 21) shows the triangle and circle are fairly good. The square is approaching a four sided figure. The final sketch of the figures by this subject (Figure 22) shows the figures with the proper number of sides; however, the triangle is truncated somewhat. One would conclude that subject 1-A benefited from the training session as pertains to the tracing and sketching of geometric figures.

Subject 1-B is a brain damaged child with poor coordination. Subject 1-B is unable to prevent her hands from shaking.

The results obtained for this subject are shown in Figures 23 through 28. This subject was bothered by the audio tone. The instructor felt that it was good for her since it immediately prompted the subject whenever she made an error. The subject learned to identify the figures. The results of the tracing show that the subject could trace the figures fairly well even at the onset of the experiment. She showed very little improvement in the tracing of the figures. This subject had a one month break in training between session four and five -- one notes that her performance has deteriorated.

The subject's initial attempts at sketching the geometric figures are shown in Figure 26. One notes that the figures all have arcs including the square and the triangle. The basic form of the circle is approximately correct. The sixth training session (Figure 27) shows very little improvement in the subject's ability to sketch the figures. Once again, they are composed of arcs rather than straight lines. The sketch of the figures by the subject after the last training session are better (Figure 28), but the square and triangle are composed of two straight lines and one arc rather than all straight lines. This subject

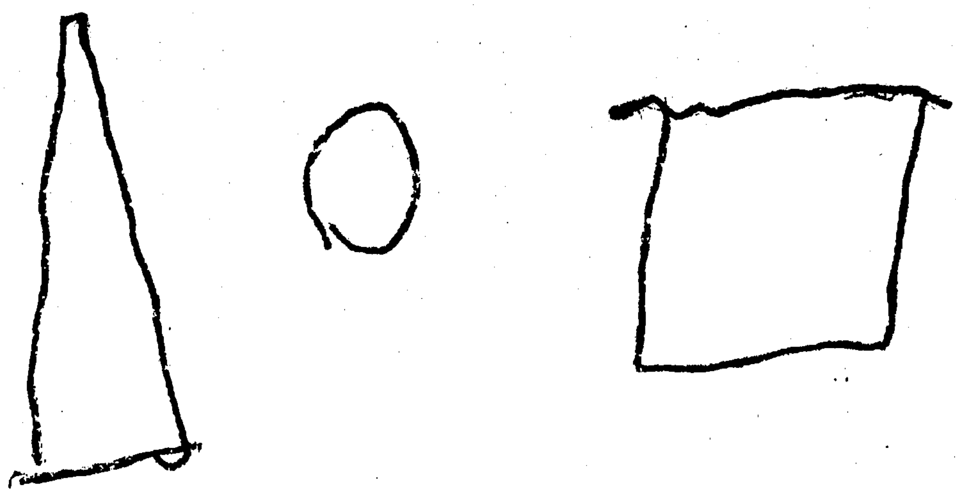


Figure 22. Subject 1-A Sketches After Session 19

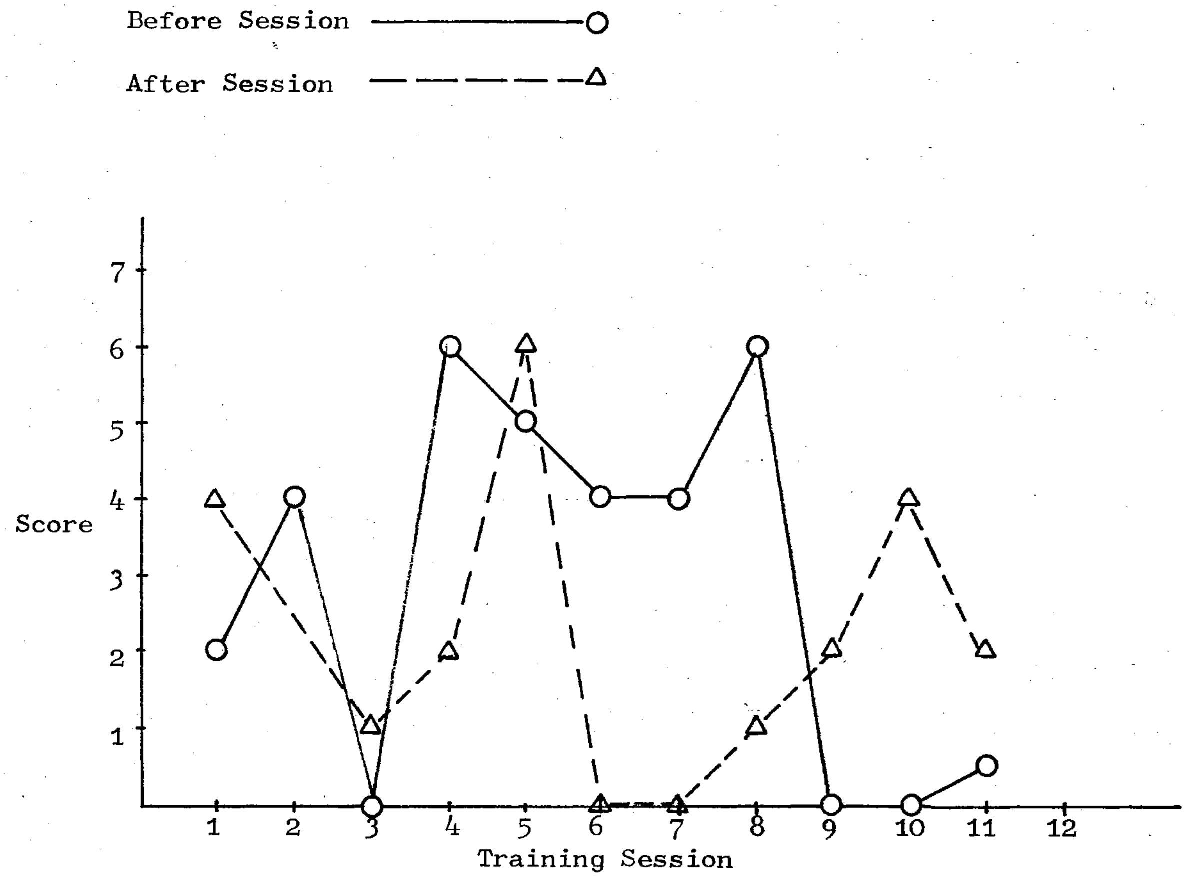


Figure 23. Subject 1-B Circle Tracing

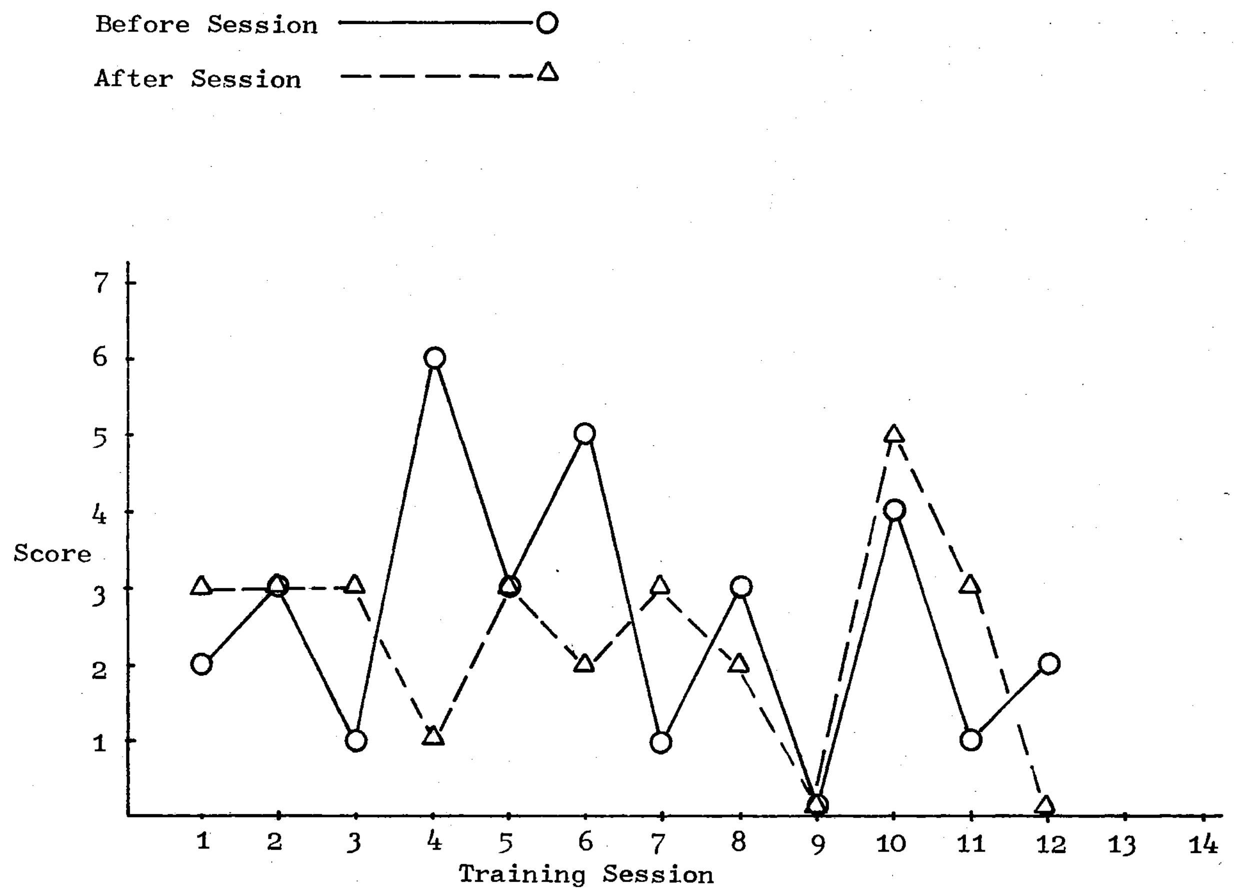


Figure 24. Subject 1-B Square Tracing

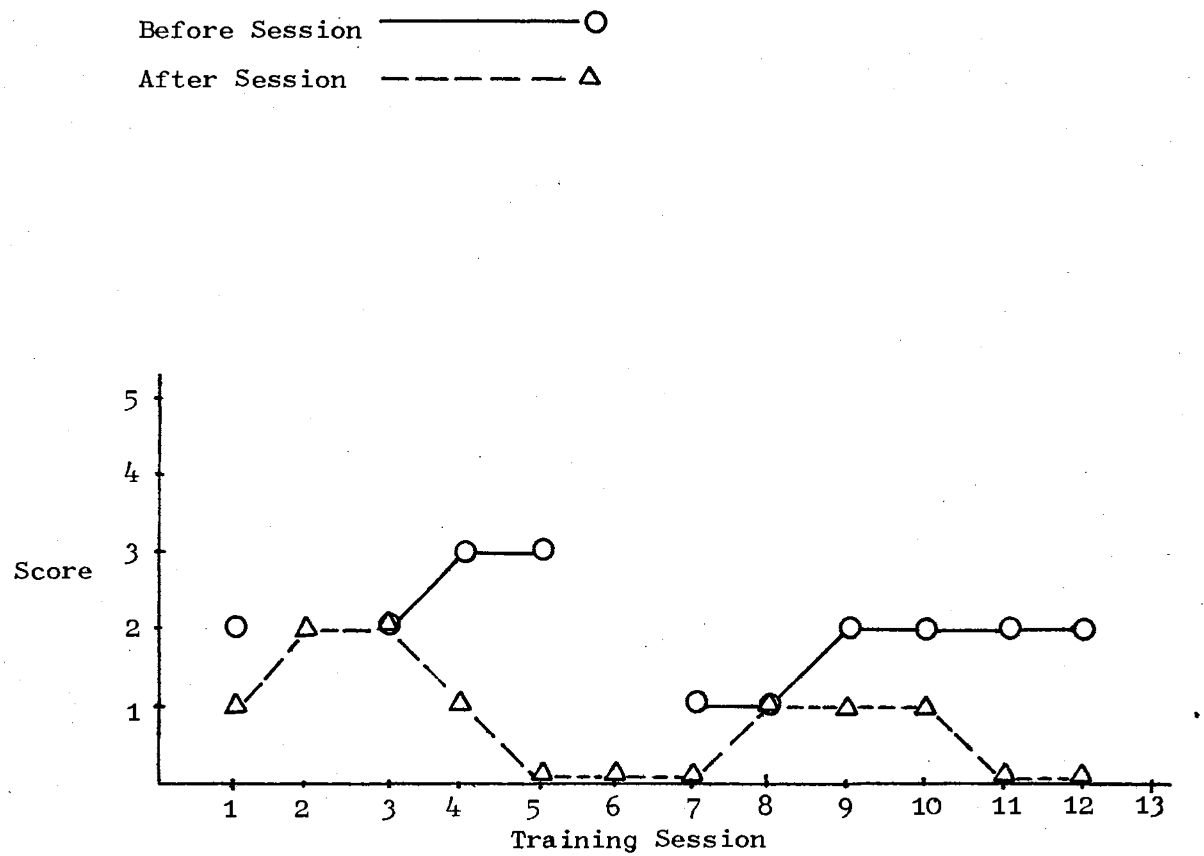


Figure 25. Subject 1-B Triangle Tracing

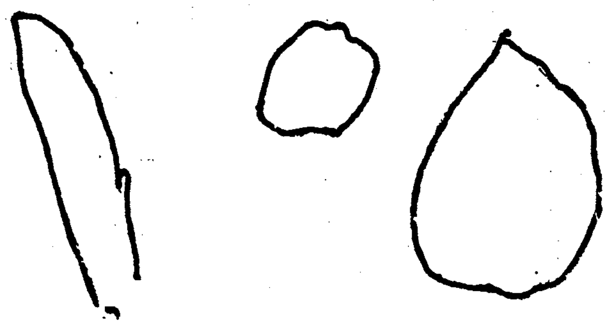


Figure 26. Subject 1-B Sketches After Session 1

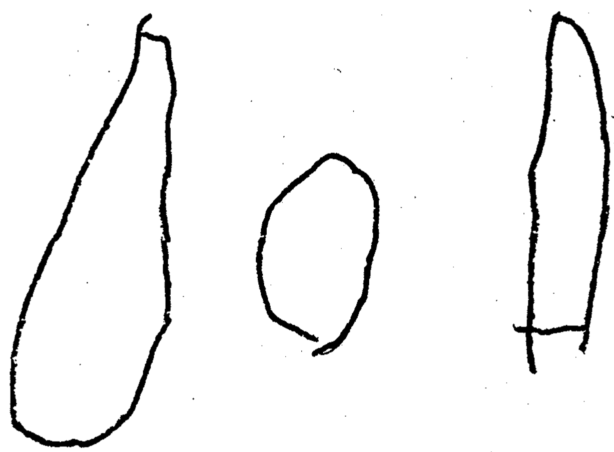


Figure 27. Subject 1-B Sketches After Session 6

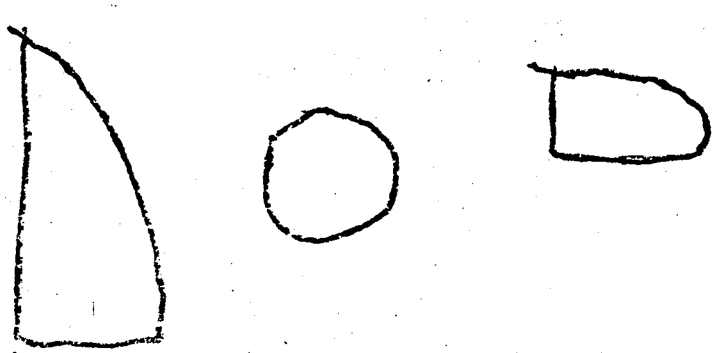


Figure 28. Subject 1-B Sketches After Session 12

was very good in tracing the geometric figures which from an engineering standpoint indicates that this system must have a reference before it can operate properly.

Subject 2-A is a brain damaged child with poor coordination. However, his coordination was superior to that of the other subjects utilized in this experiment. He was judged to have more learning ability than the other subjects involved in this experiment.

This subject does a good job whenever a task holds his interest. It is very difficult to keep him interested in a task and he had to be prompted to change figures. One notes on his tracings that he tends to get into a "do loop" and will trace the figures over and over.

Subject 2-A results are shown in Figures 29 through 34. One notes that, in all cases, this subject was proficient at tracing the figures. The training sessions did very little in the way of improving his score on the tracing portion of this experiment.

The subject's sketches at the start of the training session are shown in Figure 32. One notes that, in the case of the triangle and square, they do not represent the desired figure. The circle is fairly good.

The subject's sketches at the end of the fourth training session (Figure 33) indicate a definite improvement in his sketching ability. The triangle, square, and circle are fairly good.

The subject's sketch at the end of the last training session (Figure 34) show that he does a fairly good job in sketching the geometric figures.

The instructor commented that this subject was very restless during the training session and thinks that the audio tone might have

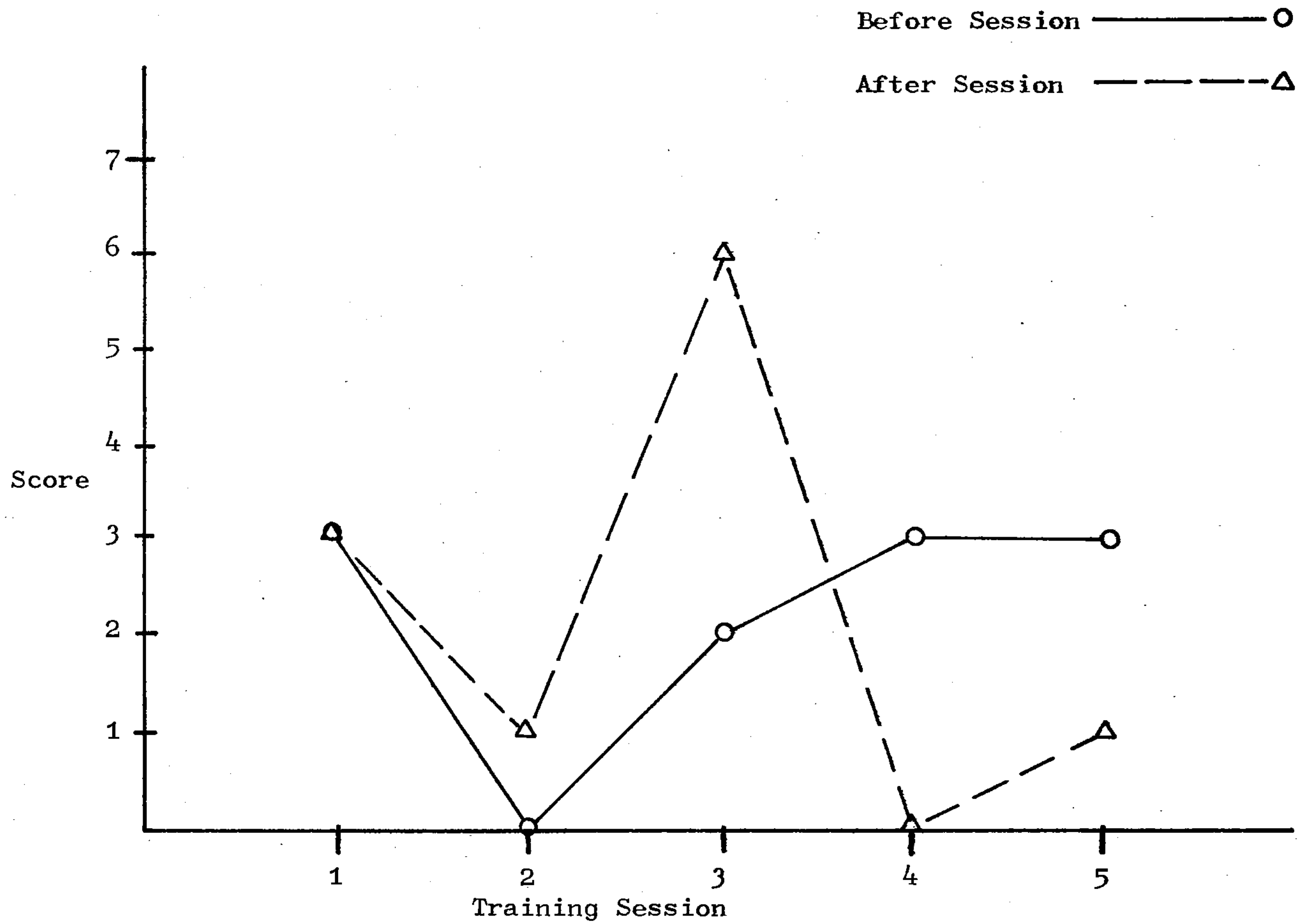


Figure 29. Subject 2-A Circle Tracing

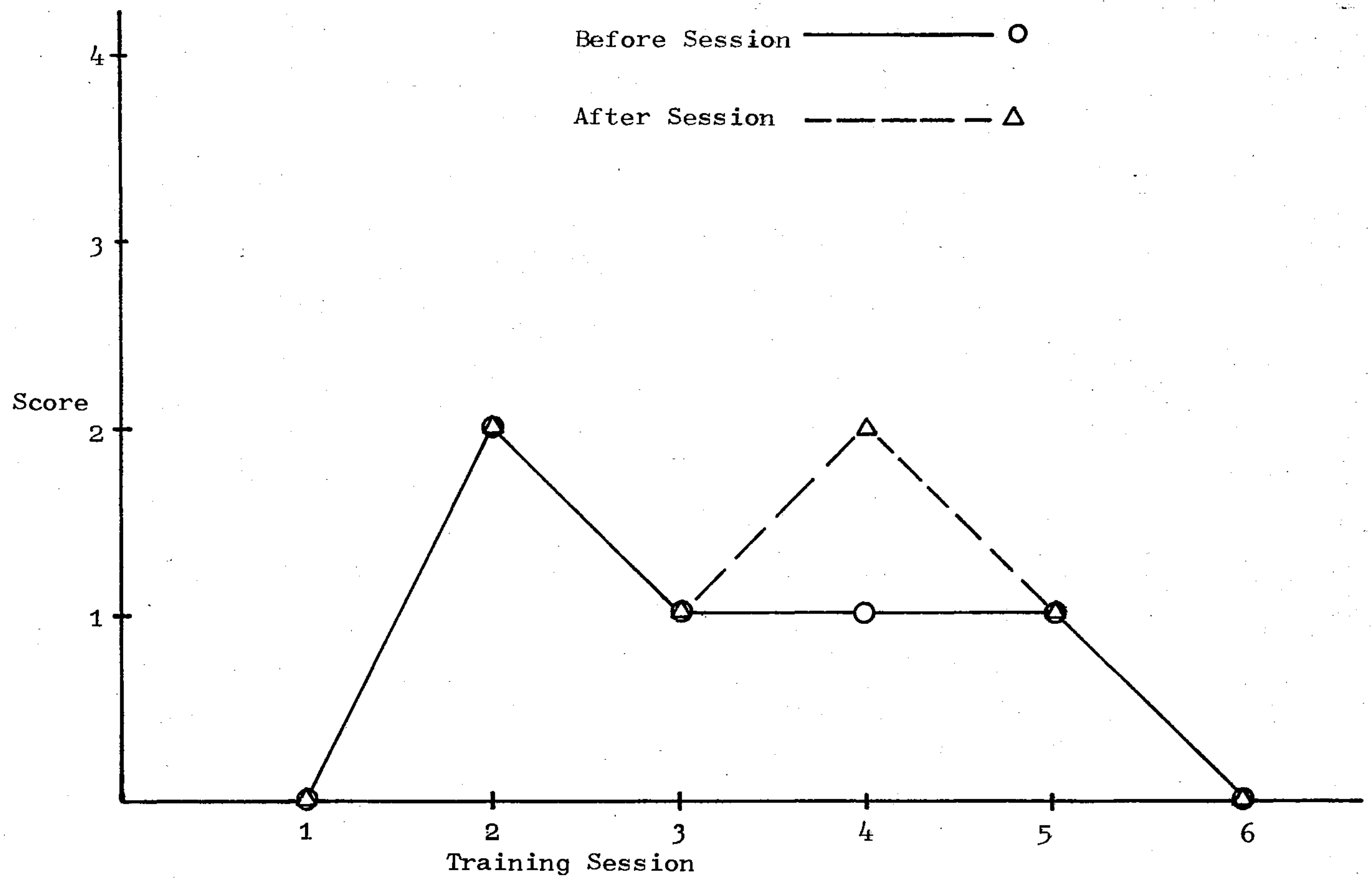


Figure 30. Subject 2-A Square Tracing

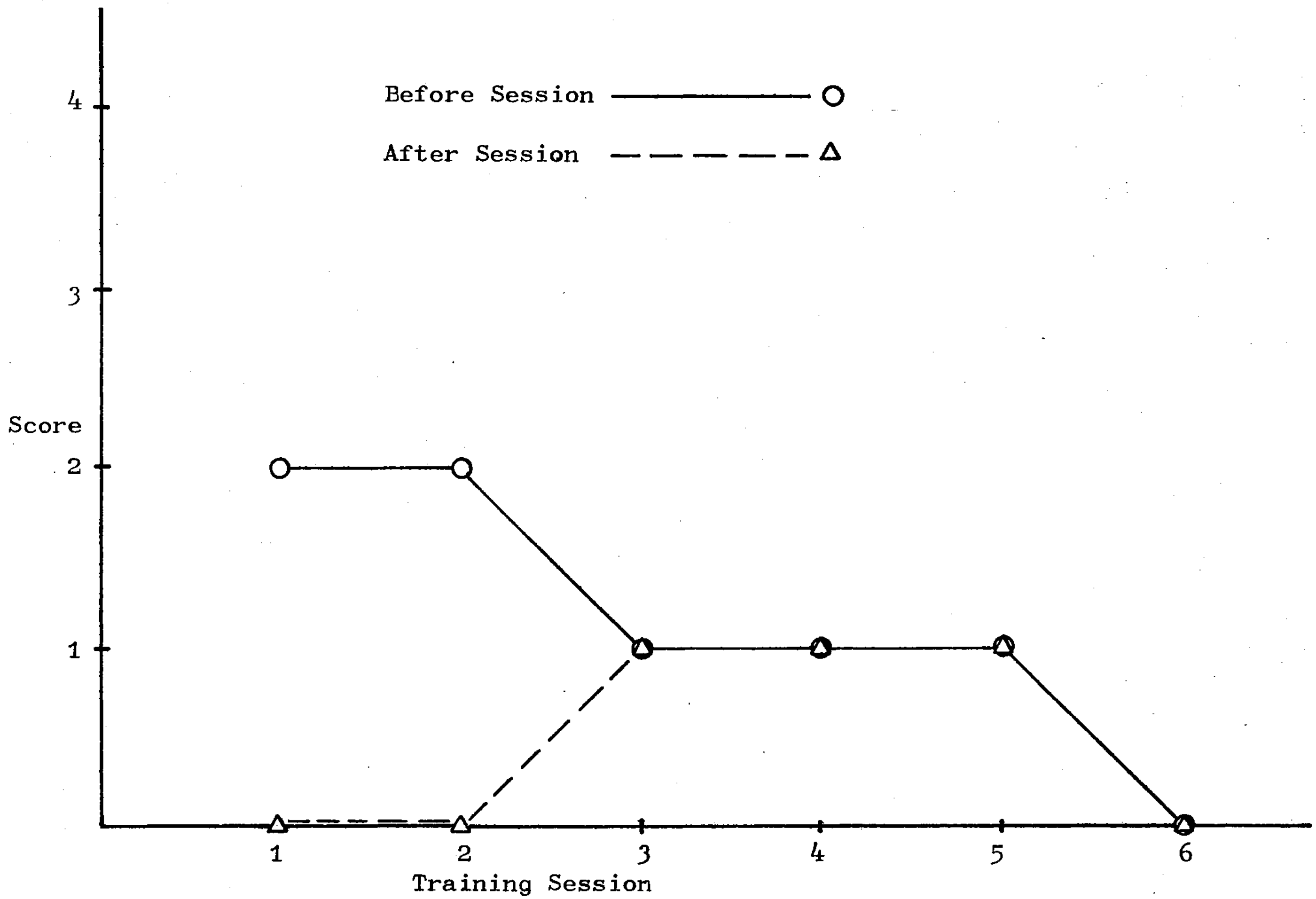


Figure 31. Subject 2-A Triangle Tracing

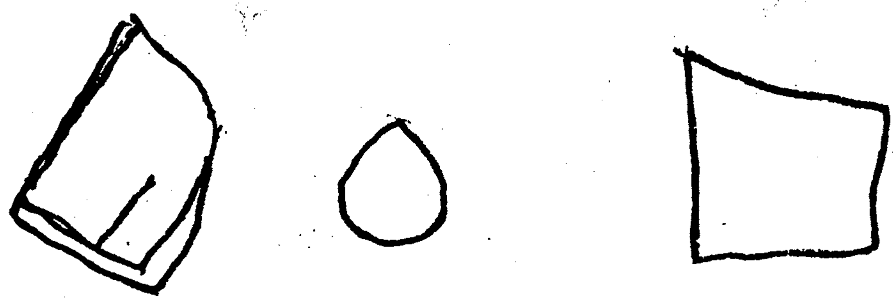


Figure 32. Subject 2-A Sketches After Session 1

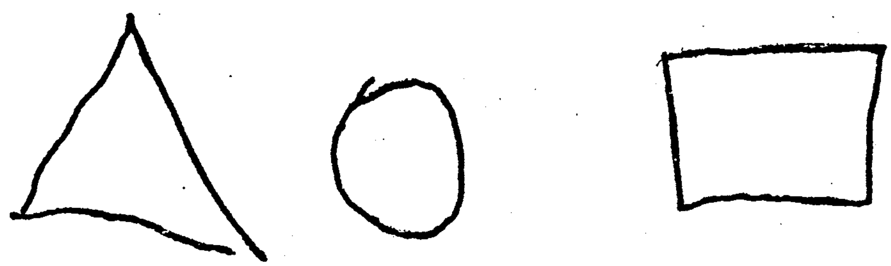


Figure 33. Subject 2-A Sketches After Session 4

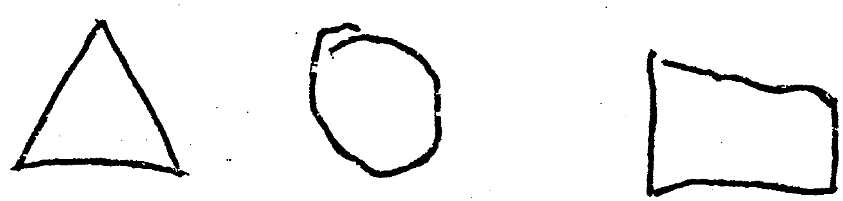


Figure 34. Subject 2-A Sketches After Session 6

been helpful. The subject was very disappointed that he was not given the audio tone.

Subject 2-B has cerebral palsy and poor coordination. This subject was very reluctant to practice without the aid of the audio tone. At the start of trraining session number 7, the student was allowed to use the tone.

This subject could already identify the figures prior to the start of the training. He is fully aware that his sketches are not correct and is quite frustrated that he cannot sketch the figures as he knows they ought to be.

The results of this subject are shown in Figures 35 through 40. His performance in the tracing of the circle varied widely during the initial training periods. He did a better job on the square and triangle, but did not show any consistent improvement. After the introduction of the audio tone during session 7, his performance improved although he was having trouble tracing the square. The subject's initial sketches are shown in Figure 38. They are very poor. However, the subject is aware that his sketches are poor.

The subject's sketches at the end of session 8 show some improvement (Figure 39). The square and circle are reasonably close to the shape of a square and circle. He has drawn a right triangle rather than an isosceles triangle. The subject's sketches at the end of the training sessions indicate an improvement (Figure 40). The square, circle, and triangle are fairly close to the proper shape.

Subject 3-A is a brain damaged child with poor coordination. This subject was given training sessions on dittoed sheets. Subject 3-A results are given in Figures 41 through 46. This subject had a very

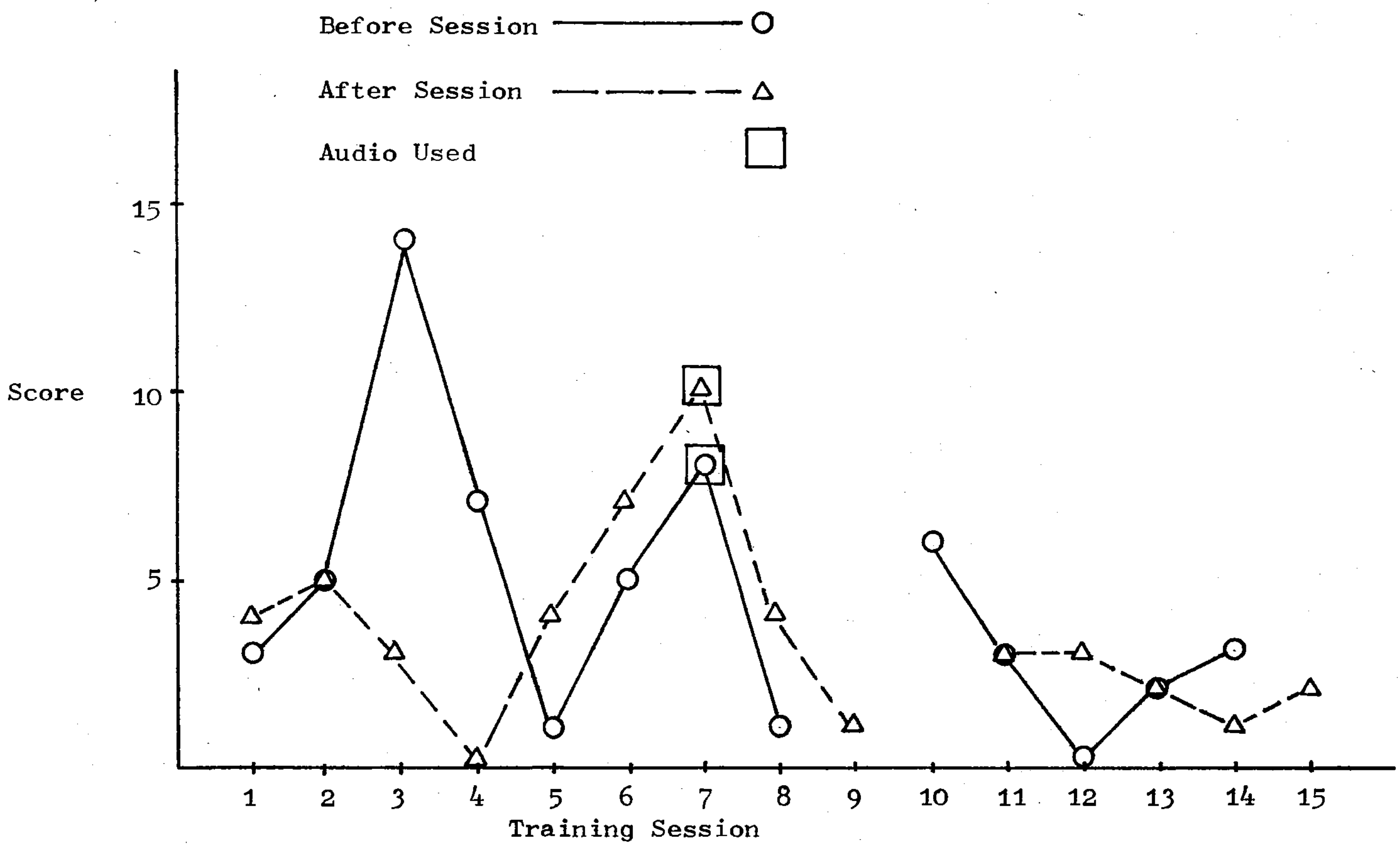


Figure 35. Subject 2-B Circle Tracing

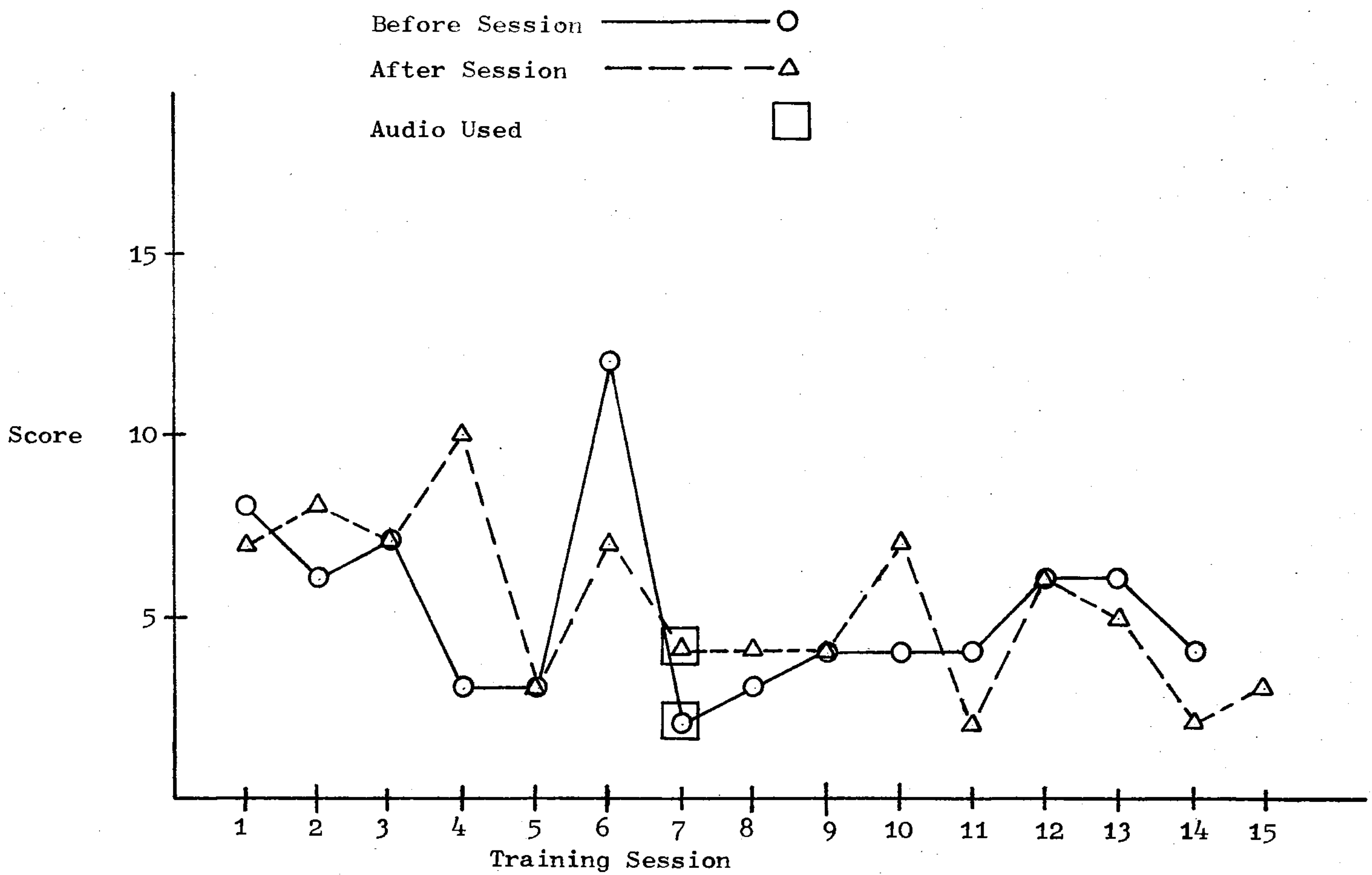


Figure 36. Subject 2-B Square Tracing

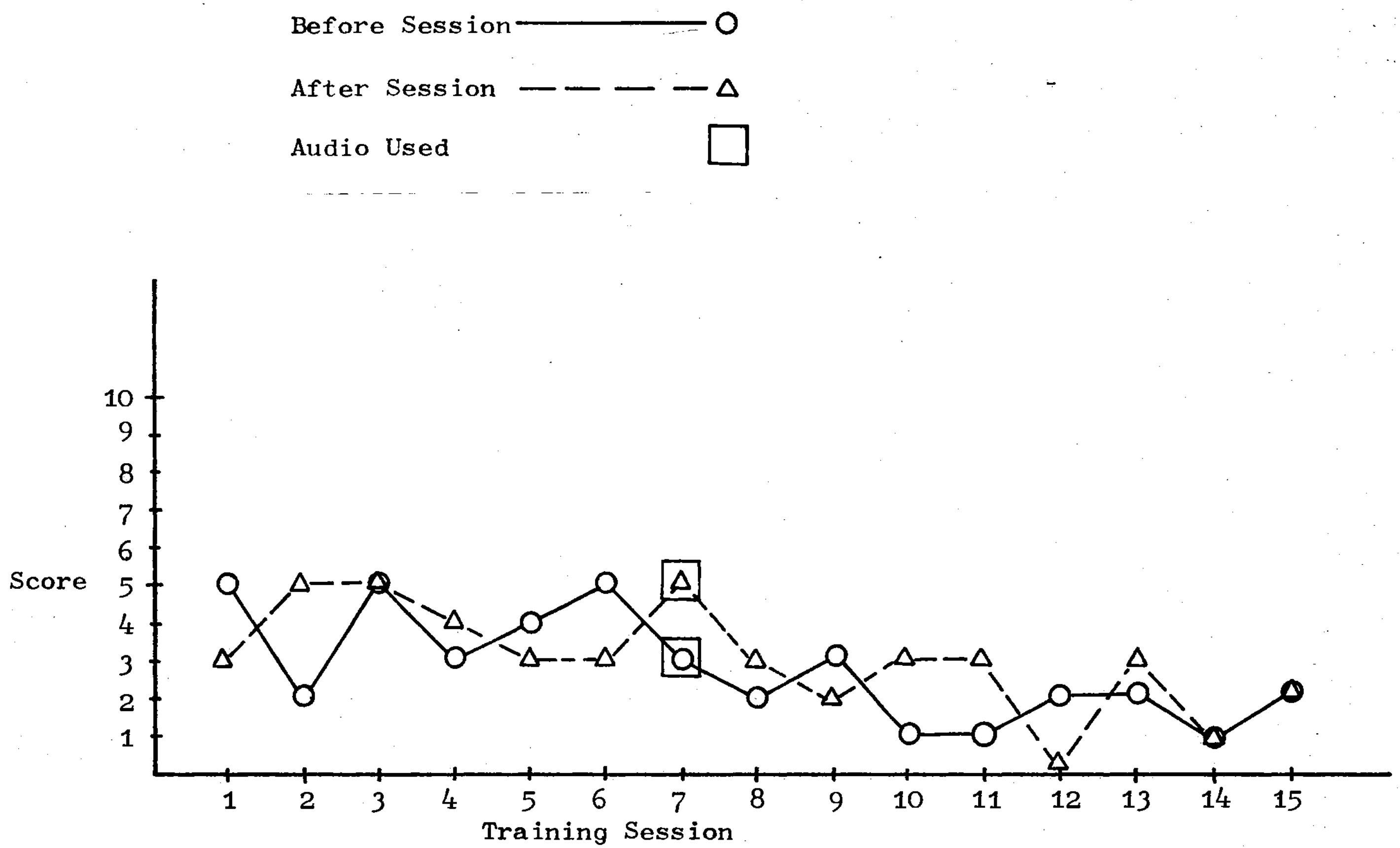


Figure 37. Subject 2-B Triangle Tracing

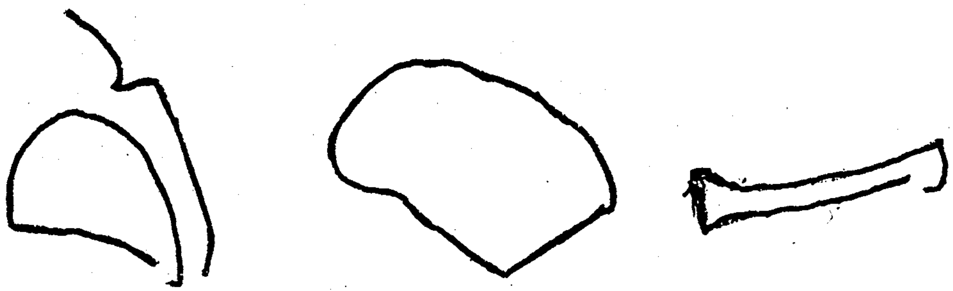


Figure 38. Subject 2-B Sketches After Session 1

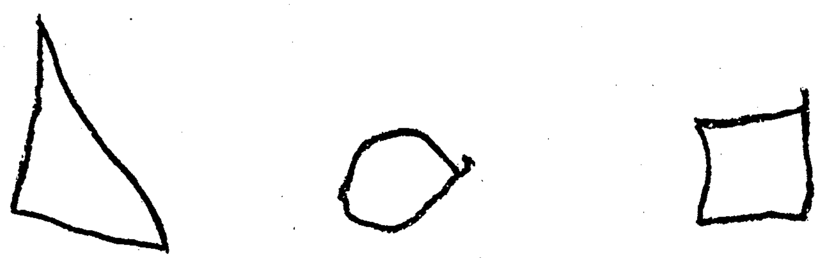


Figure 39. Subject 2-B Sketches After Session 8

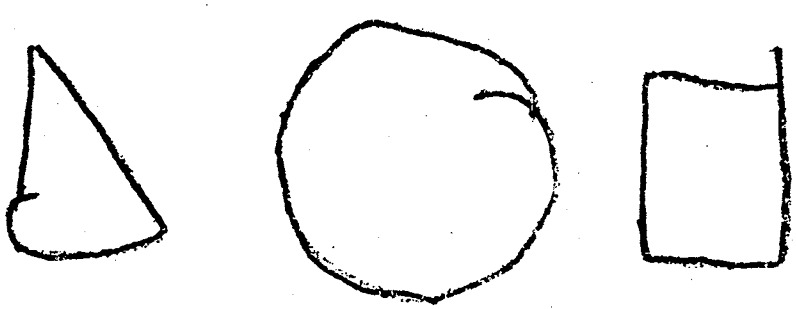


Figure 40. Subject 2-B Sketches After
Session 15

difficult time in tracing the figures. The sheet is not scored in those cases where the subject did not do sufficient work to merit a score. Very little or no improvement is noted in the subject's ability to trace the geometric figures. In the case of the circle, the subject reached a minimum score of 5 then shortly thereafter went to a score of 20.

The subject's initial attempts at sketching the geometric figures did not at all resemble the geometric figures. See Figure 44. The subject's sketches at the end of the sixth training session show improvement, but still do not closely resemble the geometric figures. The subject's final sketches indicate that he is able to draw a circle that faintly resembles a circle; however, the sketch of the square and the triangle do not resemble a square and a triangle (Figure 46). The student did learn to identify the figures.

Subject 3-B is a brain damaged child with poor coordination and limited speech ability.

The instructor would point out the figure and ask "is this a triangle, square, or a circle?" The student learned to identify the figures.

The subject's results are given in Figures 47 through 52. During session number 8 of this student, the instructor constantly reminded the student to stay on the lines.

The instructor decided to use audio on this subject at training session number 10. One notes that apparently the audiograph is acting as an error detector since its effects and the instructor reminders seem to have the effect of aiding the subject to stay on target.

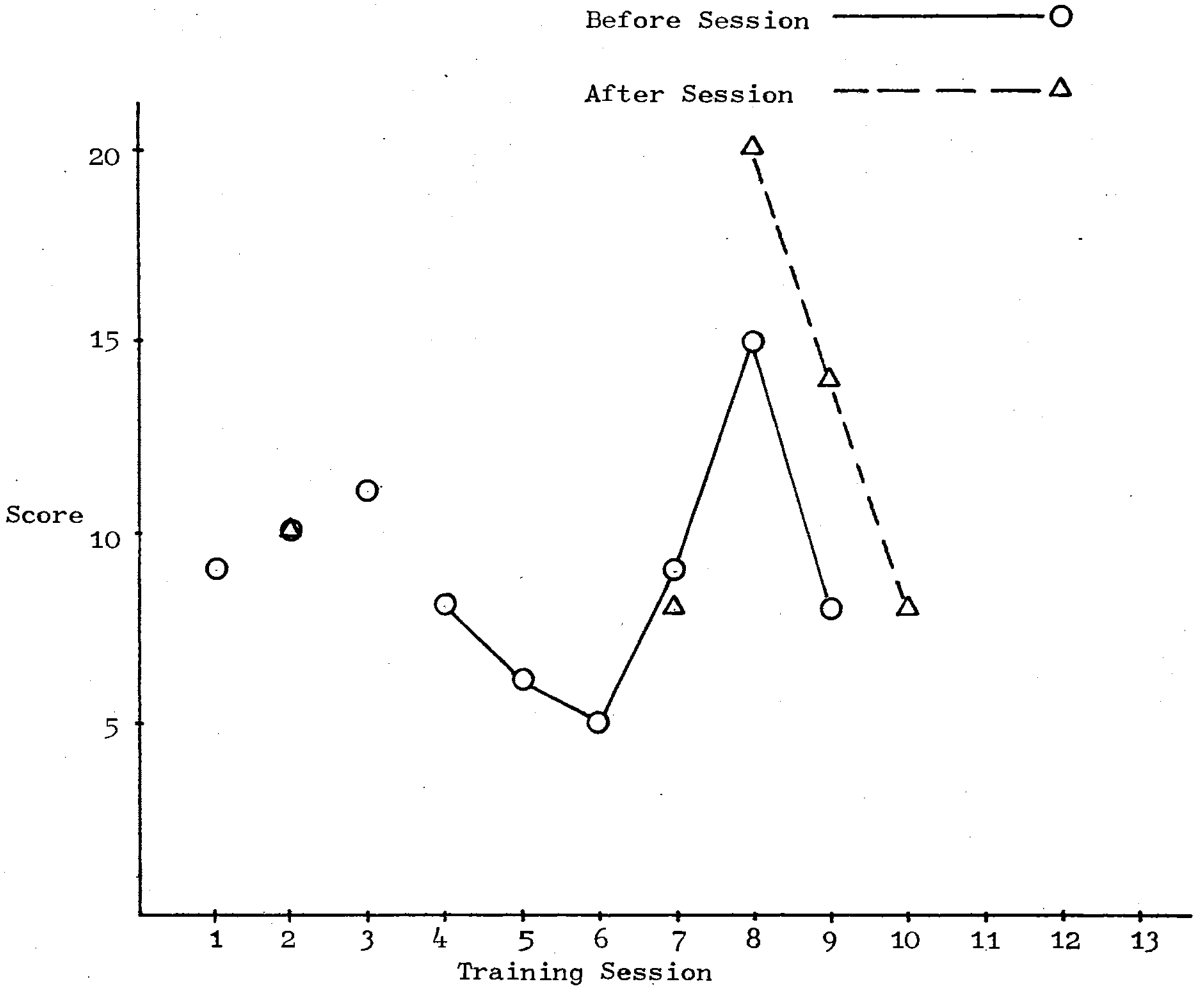


Figure 41. Subject 3-A Circle Tracing

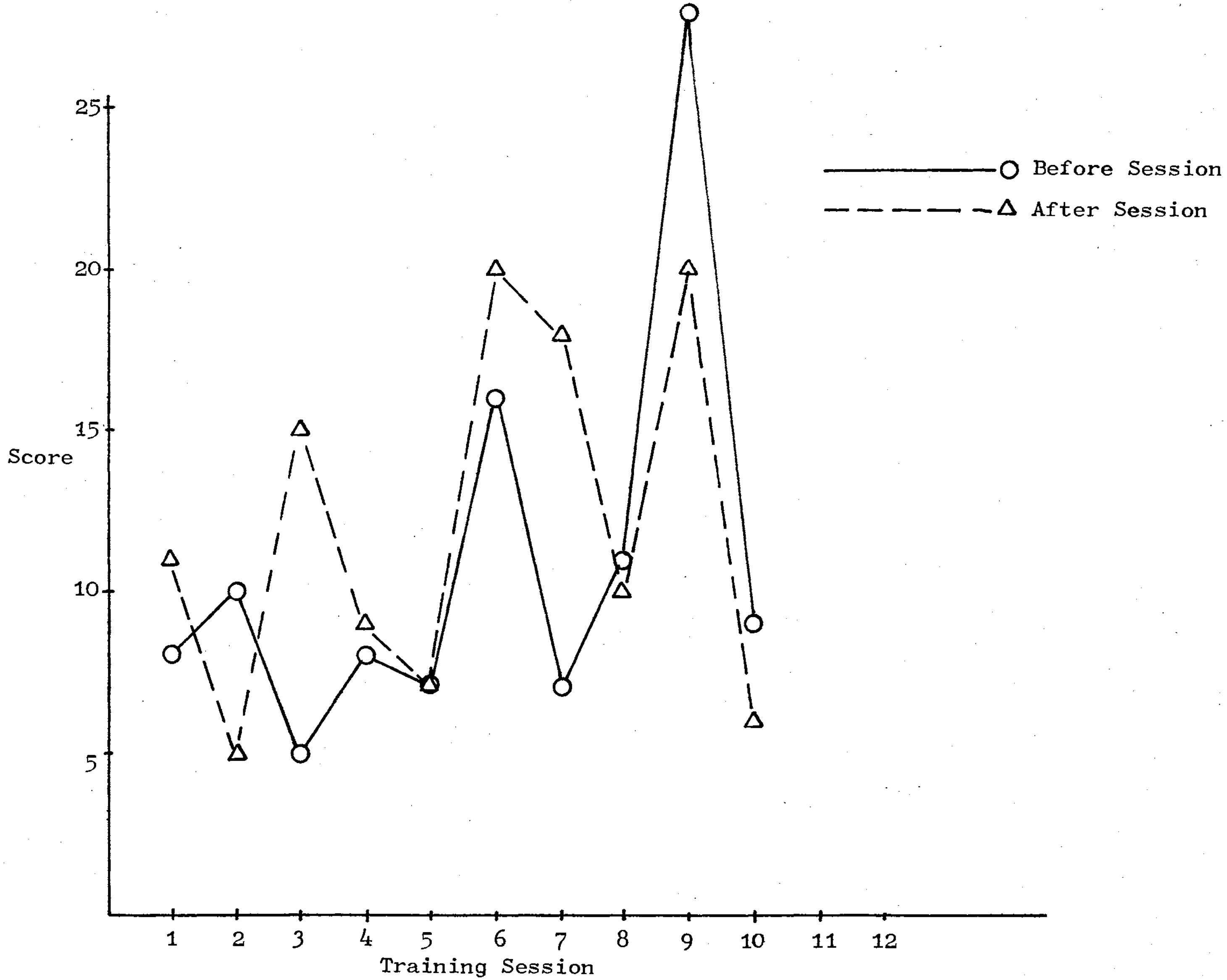


Figure 42. Subject 3-A Square Tracing

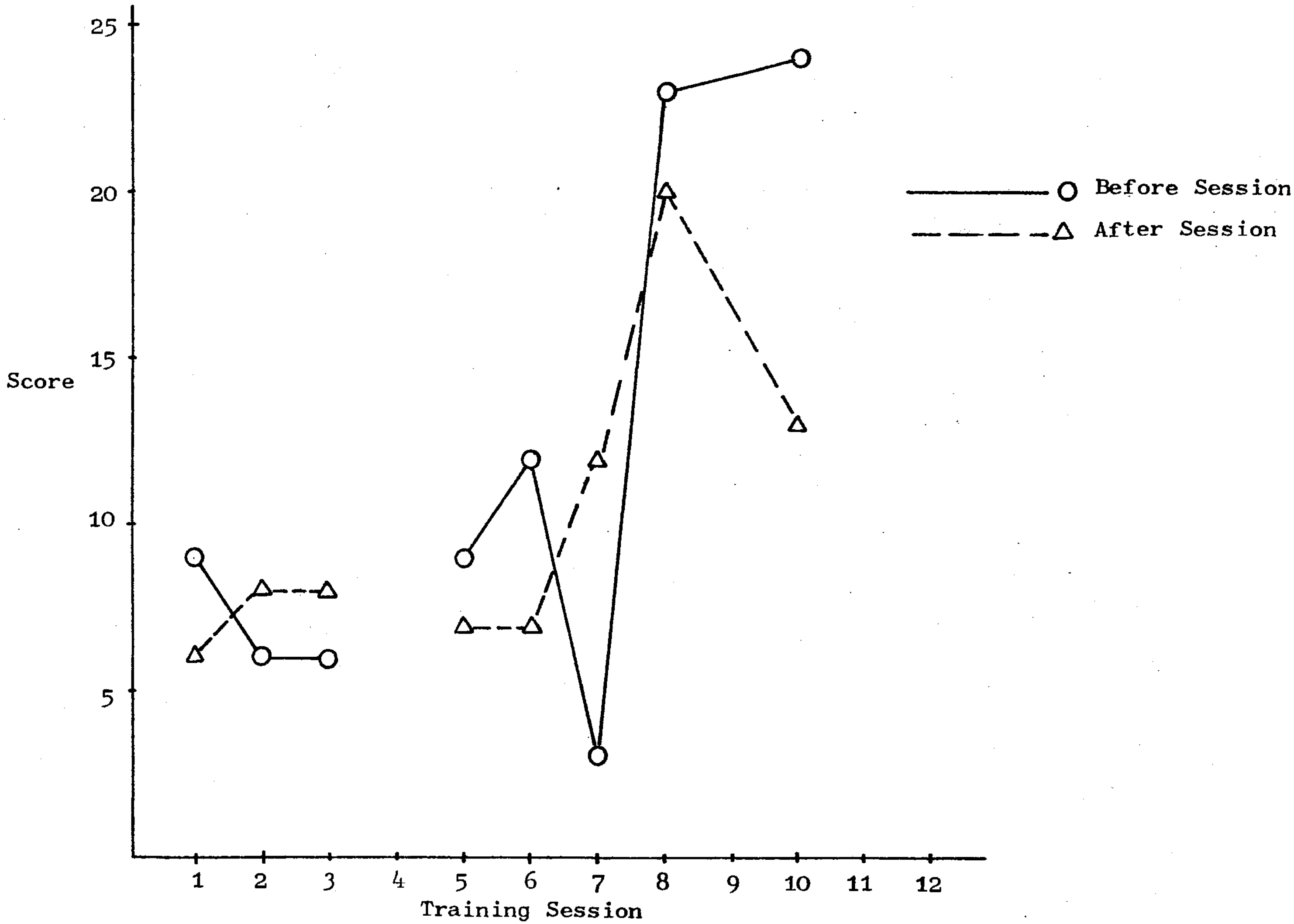


Figure 43. Subject 3-A Triangle Tracing

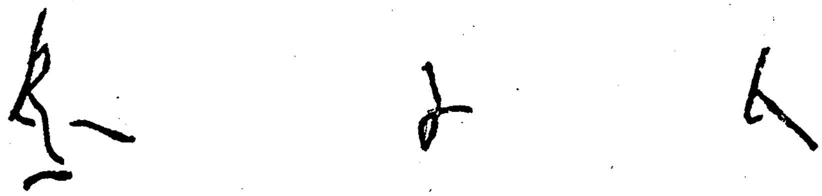


Figure 44. Subject 3-A Sketches After Session

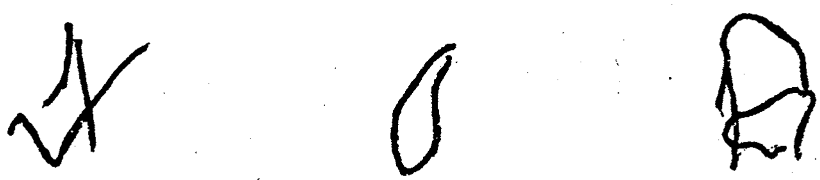


Figure 45. Subject 3-A Sketches After Session 6

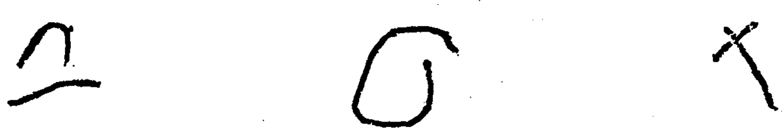


Figure 46. Subject 3-A Sketches After
Session 10

One notes an improvement in the tracing of the geometric figures after session 8. This subject had a great deal of difficulty in tracing the arcs of the circle. She did, however, show improvements as the training progressed. The subject's initial sketches are shown in Figure 50. One notes that all of the figures are combinations of arcs. The subject's sketches after training session number 6 show that the sketch of the circle although elliptical does resemble a circle (Figure 51). The square and triangle are composed of arcs but are starting to take shape. The subject's final sketches show improvement in the case of the circle (Figure 52). The square and triangle are still composed of arcs instead of straight lines.

In order to establish a control group to judge the nature of the subject's sketches, an experiment was conducted in the Altamont Public School system at Altamont, Kansas. In this experiment, three first grade children of average ability (as judged by their teachers) were given the task of learning to sketch and name the basic geometric figures including the square, circle, and the triangle.

Subject number 8 was given a 10-minute training session on the Audiograph with audio and then asked to sketch and name the geometric figures.

Subject number 9 was given a 10-minute training session on the Audiograph without audio then was asked to sketch and name the geometric figures.

Subject number 10 was given a 10-minute training session using ditto and then was asked to sketch and name the geometric figures.

Subjects 8, 9, and 10 had good coordination and, thus, had very little difficulty in tracing the figures either before or after the

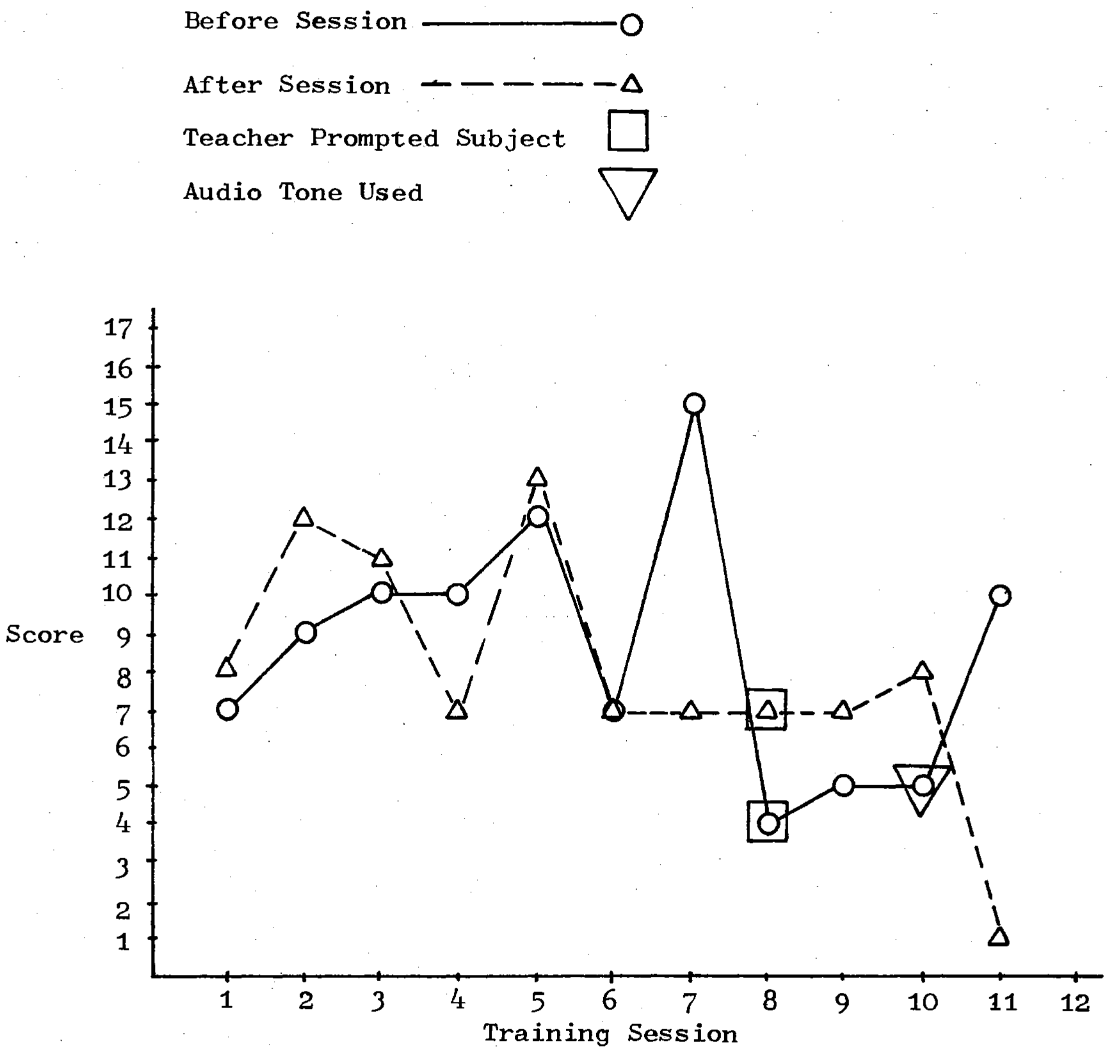


Figure 47. Subject 3-B Circle Tracing

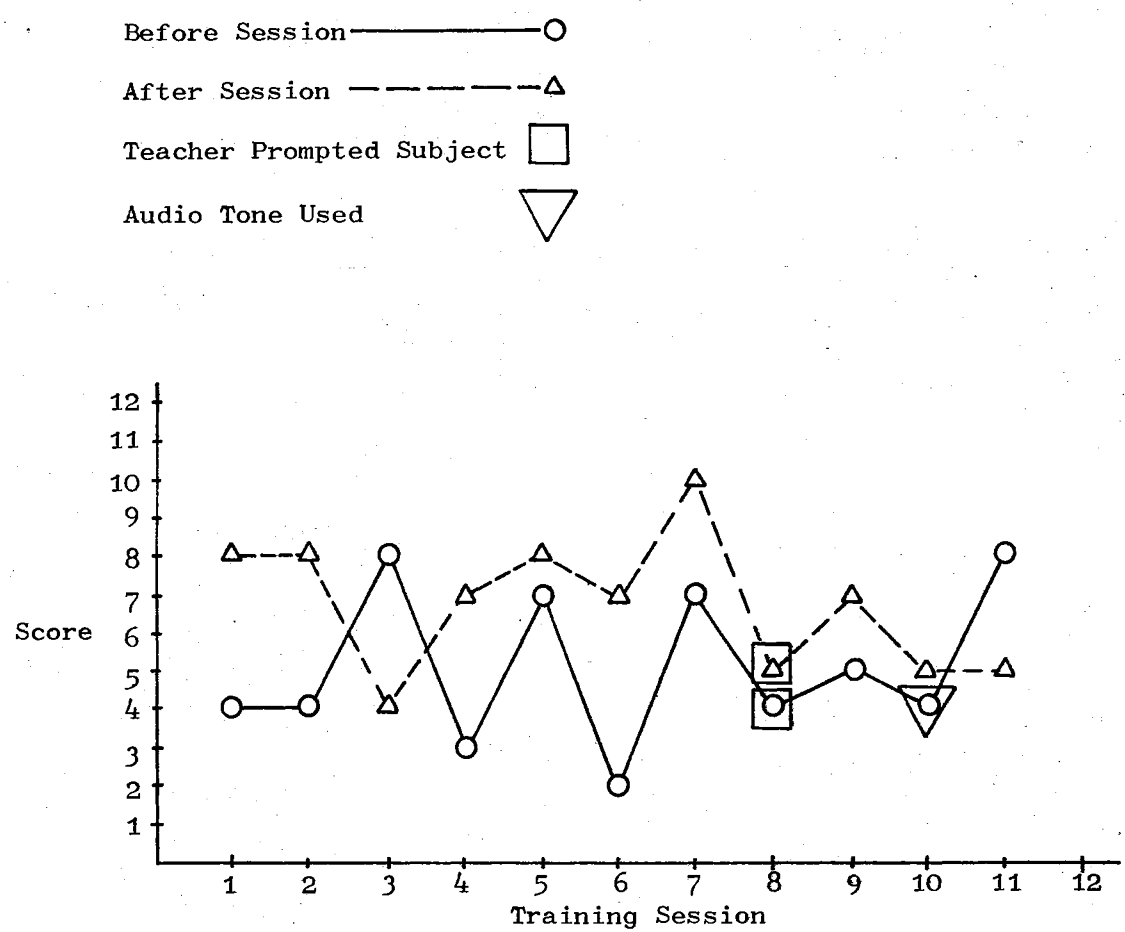


Figure 48. Subject 3-B Square Tracing

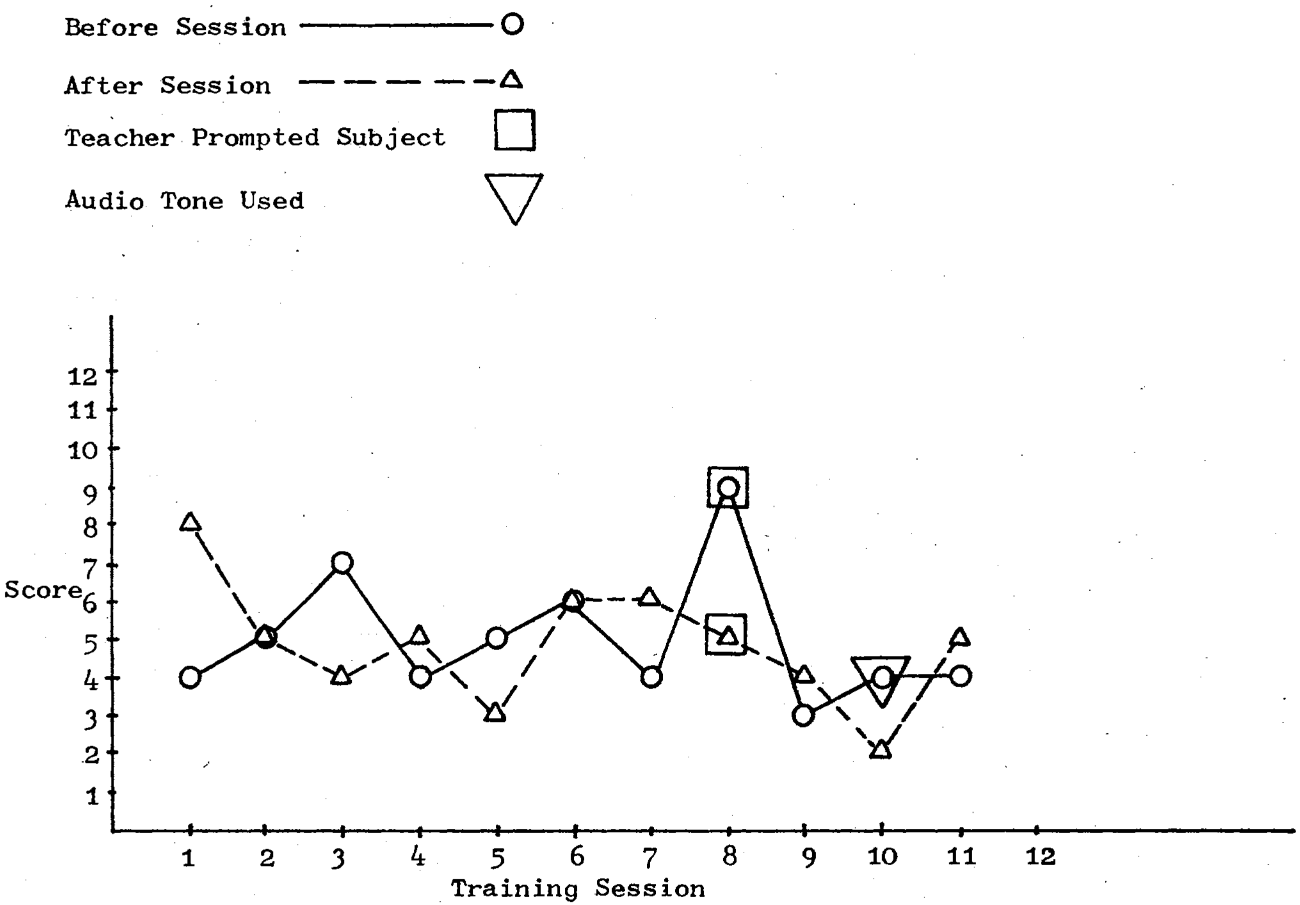


Figure 49. Subject 3-B Triangle Tracing

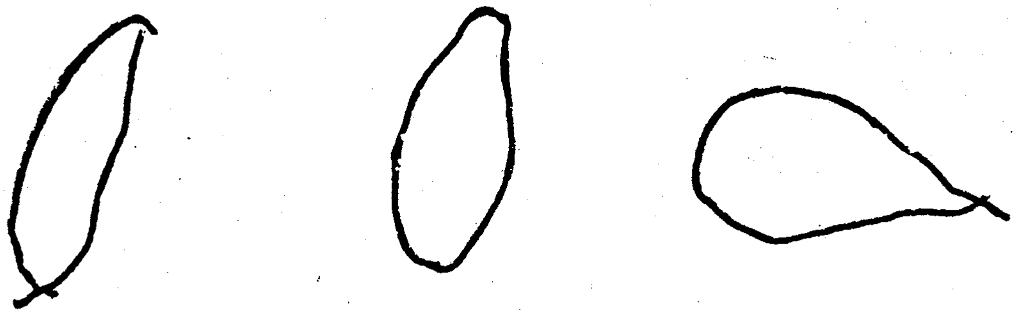


Figure 50. Subject 3-B Sketches After Session 1

Figure 51. Subject 3-B Sketches After Session 6

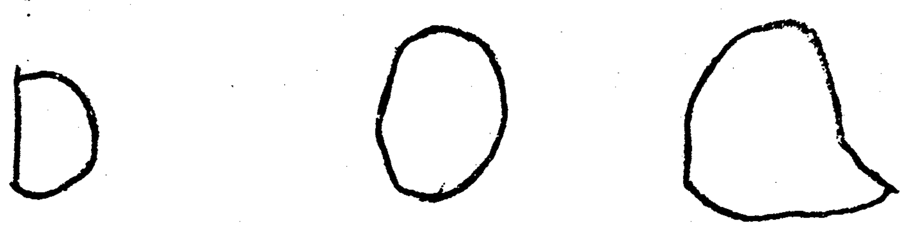


Figure 52. Subject 3-B Sketches After Session 11

training session. Their average score on the tracings was 1. Their sketches are shown in Figures 53, 54, and 55. One notes in general that they are fairly good representations of the figures. However, it is noted that the circles tend toward ellipses and that the sketches are not the same size as the reference drawings. Subjects 8, 9, and 10 all learned to identify the geometric figures.

Table II is a comparison of the scores of the subjects while performing the task of circle tracing. The task of circle tracing was chosen for construction of this table since the data indicated that the arcs of the circle were the most difficult for the subjects to trace.

TABLE II

A COMPARISON OF THE SCORES OF THE SUBJECTS WHILE PERFORMING THE TASK OF CIRCLE TRACING

Subject No.	Type of Training	Part 1 Before	Part 2 Before	Part 3 Before	Part 1 After	Part 2 After	Part 3 After
1-A	Audiograph with Audio	21	10	5	9	7	4
1-B	Audiograph with Audio	12	19	1	11	7	8
2-A	Audiograph without Audio	3	5	3	4	6	1
2-B	Audiograph without Audio	32	20	8*	15	20	11*
3-A	Dittoed Sheets	10	19	32	30	--	51
3-B	Dittoed Sheets	36	38	20*	38	34	16*

*Indicates that audio was used during this part of the training sessions.

--Indicates that performance was so erratic that no score was computed.

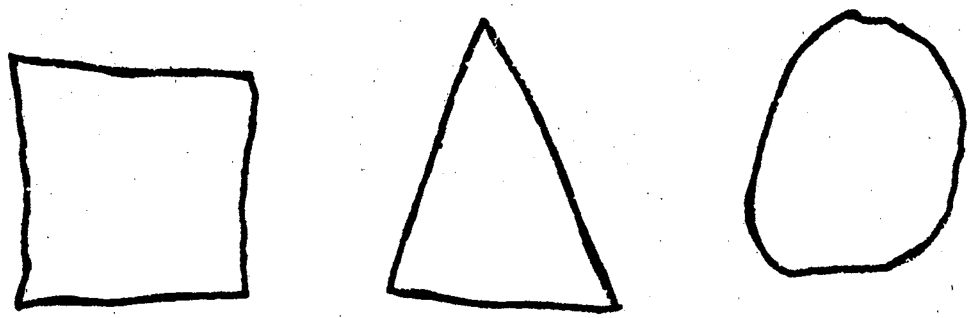


Figure 53. Subject 8 Sketches After Training

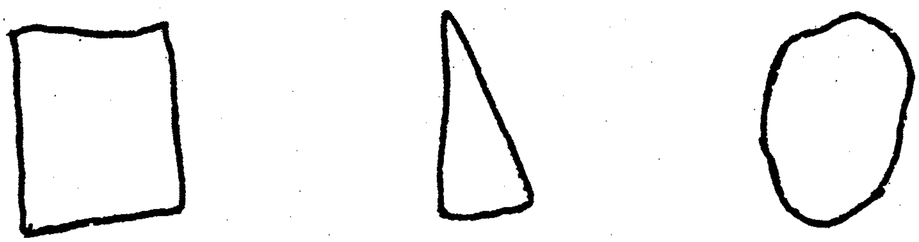


Figure 54. Subject 9 Sketches After Training

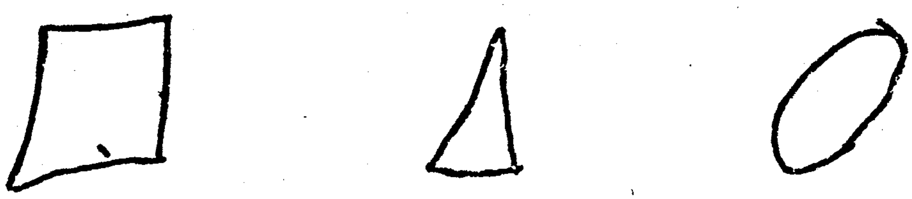


Figure 55. Subject 10 Sketches After Training

The total number of training sessions has been divided into three equal parts. The entries in the table indicates the average score of the subject prior to and after training during a particular part of the training sessions.

One notes from Table II that subject 1-A seemed to benefit from the use of the audio tone. Subject 1-B also benefited from the tone. One notes the effect of the one-month break in the training sessions for subject 1-B. This resulted in a higher score during the before portion of Part 2. However, it is noted that the student quickly adapted to training and the after score represented a decrease over Part 1.

Subject 2-A was given training on the Audiograph, but not given the audio tone. He also seemed to benefit from the training but in general, had more coordination than the other subjects.

Subject 2-B was given training on the Audiograph but was not given the audio tone. His performance improved and even greater improvement was noted whenever he was shifted to the audio tone.

Subject 3-A was given training on dittoed sheets. One notes that he has not benefited from this training.

Subject 3-B was given training on dittoed sheets. One notes that during the first two parts of the session that he had made little or no improvement in his tracing capabilities. During part three of the training sessions this subject was transferred to the Audiograph with the audio tone. One notes a dramatic drop in his score during the latter sessions.

7-6. Comments on the Results

In general, all the subjects seemed to benefit from training regardless of the group they were assigned to.

The subjects' performance markedly improved if they were supplied with an error detector. The Audiograph served this function and, thus, resulted in an improvement in performance. One notes that whenever the instructor acted as an error detector the students' performance also improved.

The Audiograph served as a motivator. Some of the subjects were quite disappointed when they found out that they were in a group that was not to be given the audio stimulus.

The Audiograph appears to be useful as a device to motivate the students and to act as a one-on-one error detector. One notes that similar results could be obtained from a one-on-one instructor to student scheme. The later procedure is not feasible from an economic standpoint.

From an engineering standpoint, one notes that feedback appeared to be of great importance in the performance of the system. In the case of the freehand sketches one noted the need for a reference input especially in the case of subject 2-B. This subject was quite capable of tracing lines, but was unable to freehand sketch the geometric figures.

7-7. The Coordination Experiment

The purpose of the coordination device was to enable the student to practice eye muscular coordination exercises with the device providing instant feedback in case the subject made an error. The feedback used in this case was a stimulus in the form of an audio tone.

The experiment was intended to evaluate the effects of the audio stimulus on the subject's performance and to note any changes in his eye muscular coordination.

7-8. The Subjects

Three subjects were used in this experiment. All of the subjects were students at the Starky Developmental Center at Wichita, Kansas. The subjects were given code names and will be referred to in this thesis by the code name rather than their given names.

Subject number 5 is a mongoloid with poor coordination.

Subject number 6 is a mongoloid with poor coordination.

Subject number 7 is a mongoloid with poor coordination.

7-9. The Experiment

In this experiment, the subjects were required to thread a loop of 3/4 inch diameter over a 1/16 inch diameter wire shaped into a slight spiral. The instructor would count the number of times that the audio signal would sound as the student attempted to thread the loop over the wire. If the count exceeded 10, the instructor quit counting and marked a score of 10+ in the evaluation sheet, Figure 15. At least two counts of the students performance were made during the training session. The nominal time of the training session was 5 to 10 minutes. A count was normally made near the start of the training session and at the end of the training session. The subjects were given training and evaluated at least twice a week. The instructor made such comments as she deemed appropriate in the space provided on the evaluation sheet.

The evaluation of this experiment is based upon the instructor comments since they lay the ground rules for a particular subject and expose items that cannot be covered by a simple count.

7-10. Results

A subject-by-subject discussion of the results will be given.

Subject number 5 is a mongoloid with poor coordination. This subject used both hands during the experiment and was sitting down. This subject was left handed and the instructor noted in session number 4 that the subject performed better if the loop was initially pointed to the left. Subject number 5's results are given in Table III.

TABLE III

SUBJECT NUMBER 5 RESULTS

Session	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1st Count	10+	9	8	9	7	8	7	8	3	6	5	4	4	0	2	0	1
2nd Count	10+	10+	8	7	5	0	8	6	5	0	2	5	2	3	2	0	0

Subject number 6 is a mongoloid with poor coordination. This subject's results are given in Table IV.

TABLE IV

SUBJECT NUMBER 6 RESULTS

Session	1	2	3	4	5	6	7	8	9	10	11	12	13
1st Count	10+	10+	10+	7	8	10+	10+	10+	10+	10+	9	10+	10+
2nd Count	10+	10+	10+	9	8	5	7	10+	10+	8	10+	6	10+

Subject number 7 is a mongoloid with very poor coordination. This subject on his initial tries continually touched the loop, thus, receiving a continuous audio tone. The subject then stood up and seemed to have better control over his actions.

The results of this subject are given in Table V. It is apparent that, in the case of this subject, a higher number than 10 should have been chosen for an upper limit since most of his scores were 10+. However, the instructor noted in her comments that the subject was improving in his performance.

TABLE V

SUBJECT NUMBER 7 RESULTS

Session	1	2	3	4	5	6	7	8	9*	10	11
1st Count	10+	10+	10+	10+	10	10+	10+	10+	10+	10	10
2nd Count	10+	10+	10+	10+	11	10+	9	9	10+	7	8

*The instructor noted that the subject was hyperactive this day and was not doing his work in his usual manner.

7-11. Comments on the Results

Each subject that participated in this experiment showed an improvement in the eye muscular coordination required by the coordination game.

Subject number 5 made the most dramatic improvement and it is expected that in the future he will be required to use a smaller loop than the 3/4 inch utilized by the coordination game.

The coordination game seems worthwhile from the standpoint of motivation. The subjects enjoy trying to thread the loop and as a byproduct are doing an eye muscular coordination exercise.

The game acts as an impartial reference and gives an audio stimulus whenever an error is made.

The difficulty of the task may be programmed to fit the needs of a particular subject. For example, subject number 5 apparently needs a smaller loop in order to make the task more challenging to him. Subject number 6 and subject number 7 apparently needed a larger loop.

The difficulty of the task should be such that it challenges the student, but is not so difficult that the student feels that it is hopeless for him to attempt the task.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

8-1. Summary

A comprehensive literature survey into the existing electronic and electromechanical aids for the handicapped indicated that a great deal of progress has been made in the area of electronic and electromechanical aids for the visually handicapped and for the physically handicapped.

In the case of electronic and electromechanical aids for the visually handicapped, the aids fell into three broad classes. Those devices that are intended to enable the blind person to read printed material, those devices that are used to enable the blind person to follow a path and have knowledge of that path when he is walking, and those devices that are intended to enable the blind person to "see". The advent of micro-electronic and dependable battery supplies has aided the development of these devices.

Each of the above mentioned aids for the visually handicapped make use of other senses to convey information to the handicapped individual. Typically, the channels used are the auditory channel and the tactile channel. Evidence exists indicating that many of the earlier tactile reading devices were bandwidth limited, i.e., did not have sufficient bandwidth to effectively convey the necessary information. The reading rate using the tactile devices varied from 15 words per minute to 60 words per minute. This rate, while certainly is much better than nothing, is still so slow that it is uncomfortable for the person doing the reading.

An experiment was conducted in which five sighted individuals were required to read aloud a passage from a book under the conditions that only one letter of word was exposed at a time and the individual was required to do his own scanning. The reading rate obtained under these conditions ranged from 22 to 36 words per minute. Each of the subjects complained that this reading rate was so slow that it was very uncomfortable.

This indicated that those subjects using single letter scanning tactile devices who read at a rate of 20 words per minute were doing quite well. In addition, the reading rate of 60 words per minute were performing at a remarkable rate.

The devices utilized to enable the blind to see are still in the laboratory stage. They involve a videocon camera and use a rather large area of the back as the point of tactile stimulation. The vision is to a great extent 2-D although there is some evidence that 3-D vision is possible. The visual acuity of this device is 20/600 and when one considers that a person is considered legally blind whenever his vision is 20/200 he begins to appreciate the magnitude of the problem.

Bio-electric prosthetic control systems were investigated and it was noted that there has been progress in this area. The matter of the man-machine interface is still the primary problem. Those systems that tie directly into the nervous system are still in the very early experimental stages.

A great deal of research has gone into the area of the pick-up probes. By and large the conductive probes are unsatisfactory due to the irritation caused by the conductive jelly. Work is proceeding in the area of capacitive pick-up probes.

More basic research is needed in the definition of the nature of the bio-electric signals. For example, what is the nature of the signal that causes one to twitch a finger as opposed to the signal that causes the hand to grasp an object?

The systems engineer, in dealing with prosthetic devices, is faced with a problem involving a lumped and a distributed parameter system. The exact dynamics of the biological system are not well defined indicating that more basic experimentation is needed in this area.

The development of electronic and electromechanical aids for teaching the mentally handicapped has been primarily concentrated in the area of teaching machines. Teaching machines are uniquely applicable to the training of the mentally handicapped; however, their price has mitigated against their widespread use. Teaching machines would be especially useful in the home of the retarded child, but again this is not economically feasible with most of the present day devices.

The Audiograph, a teaching aid for the mentally retarded, was developed in conjunction with this thesis. This device is designed to aid in the development of the visual muscular coordination skills needed by the retardee in order to be able to write. The student is required to trace a template with a probe and if he makes an error is given an audio stimulus.

An evaluation of the Audiograph at the Starkey Development Center at Wichita, Kansas, indicated that the device has merit. It is especially useful in motivating the students to practice the repetitious boresome exercises that develop the necessary eye-muscular coordination used in the task of writing. The Audiograph serves the purpose of an error detector and gives the student an audio stimulus whenever he strays from the confines of a prescribed template.

It was noted that often the students were unaware that they were making a mistake when tracing a figure or letter. In addition, they often started the task without being on the lines of the figure they were required to trace.

The coordination game developed in conjunction with the Audiograph was useful in motivating the students to practice eye-muscular coordination exercises. In this case, the exercise consisted of trying to thread a loop over a spiral wound wire. If the student touched the wire with the loop, he was given an audio tone to indicate that he had made an error.

The difficulty of the task involved in using the Audiograph can be varied to fit the capabilities of a particular student. If the student has very poor coordination, he would be started out on a template with wide grooves and in the coordination game a large loop and a wire that is nearly straight. The limits of the acceptable error region would be narrowed as the student's performance improved.

The price of the Audiograph in kit form is less than five dollars making it well within the reach of most of the handicapped children. This device could be used in the home by the relatives of the handicapped child and would act as an important adjunct to the in-school training of the child.

8-2. Observations

It was noted that although the retarded subjects seemed to have difficulty in learning to perform routine tasks, they seemed to have very little difficulty in learning how to operate the Audiograph. In particular, they quickly learned how to connect the Audiograph such that it would give them an audio tone whenever they touched the template.

Secondly, it was noted that most of the subjects were fully aware that they were not sketching the geometric figures in the proper fashion. They seemed to have a mental picture of how the figure should look but were unable to command their visual-muscular coordination system well enough to create the geometric pattern.

In particular, one subject started to sketch a triangle from the left hand corner up but could not get the line from the right hand corner to intersect with the line from the left hand corner. He then in desperation placed his left hand such that it intersected the right hand line and traced along his hand in order to close the figure.

It is noted from a consideration of Figures 53, 54, and 55 that the sketches of subject are nearly equal in size to the reference figures. The sketches of subjects 8 and 9 while correct geometrically are not the same size as the reference figure. Subject 7 was given instruction on the Audiograph.

8-3. Conclusions

The development of electronic and electromechanical devices to aid the handicapped has made some important strides during the last ten years. The advent of integrated circuits and dependable battery supplies has been responsible for a good deal of this progress.

It appears that a good deal of the effort in the development of electronic and electromechanical aids for the handicapped has been based on "seat of the pants engineering" and that a good deal of basic research needs to be done.

A number of the more sophisticated devices mentioned in this thesis are still in the laboratory stage and exist only as laboratory prototypes.

The primary factor that retards the production of electronic and electromechanical aids for the handicapped is the fact that the market at best is marginal.

For example, in the case of the visually handicapped person, the data taken in 1970 indicated that there were 1,090,000 severely visually handicapped persons in the United States. Of these persons, 56 per cent have an annual income of less than $3,000 and 75 per cent have an annual income of less than $7,000. Thus, when one considers the number of visually handicapped people and their annual income, it becomes apparent that the market for expensive electronic aids is going to be marginal if the handicapped individual is required to purchase his own device.

The engineer's role in the development of these aids for the handicapped is somewhat different than his traditional role. He will have to learn to communicate with the physiologist and the psychologist. The best design from a hardware standpoint may not be the best when considered from a human standpoint. As is true in most other fields reliability, durability, utility, and price are factors that determine the success or failure of a particular device.

The Audiograph experiment indicates that this device has merit as a training aid for the mentally retarded. It serves to motivate the student to practice boresome repetitious tasks. It acts as an impartial error detector and will give an audio stimulus whenever an error is made. Finally, in the words of an instructor at the Starkey Development Center, "At the very least, it serves the purpose of constructive busy work."

Thus, the Audiograph has demonstrated that it is possible to develop a device that serves a particular need at a price consistent with realities of the economic situation.

In the future, the engineer may decide to design, build a prototype, test it, then offer the plans or kits to the relatives of the persons who have need of a particular device.

At first glance, it may seem that 30 devices costing $5 each and that have different functions are just as expensive as one multifunction device costing $150. However, the fact is that 30 different people can simultaneously use the single function devices while only one or two can simultaneously use the multifunction device. Thus, in a training institution it may be more practical to consider several single function devices rather than one multifunction device.

8-4. Suggestions for Future Study and Development

As a result of the literature survey into travel aids for the blind, it will be noted that the device proposed to aid the blind to cross a parking lot or open area in a straight line involved the use of a radio tuned to a local station. The ferrite antenna of the radio acted as a nulling device and enabled the user to travel a straight line within five degrees of nominal.

It would seem that a much simpler more straight forward unit could be devised by using a compass with directional alarms which would sound whenever the user strayed from a preset direction.

In connection with the Audiograph, one could use it in a testing situation by installing counters and timers to record the total time required to perform a prescribed task, the number of errors made in the performance of the task, and the time involved in each error.

An experiment could be performed to test the merits of the Audiograph in the public school system. In particular, it would be of interest to determine whether or not the use of the Audiograph influenced the size of the freehand sketches of the students as compared to the reference sketch.

The Audiograph made use of the audio tone as a stimulus to the subject whenever he or she made an error. The author of this thesis is presently engaged in an experiment in which the audio stimulus is used in connection with the training of industrial workers to operate punch presses. In connection with this experiment, a punch press was stimulated and error detectors were so connected that it is possible to record the total number of parts that the operator produces, the total number of bad parts that he produced, and the number of accidents that the operator had during the training session.

The press is so constructed that having an accident does not cause the trainee to lose a finger or hand but instead he is given a loud blast on a horn whenever the situation indicates that he would have been involved in an accident.

It would seem that the above mentioned area would be a fertile field for future study. For example, one of the problems facing the present society is the retraining of individuals to perform other jobs. It appears that it would be helpful if there were reasonably priced training aids available that would eliminate the danger from the performance of the task, yet places the trainee in a realistic training environment.

Another possible use for such devices would be in pre-employment screening tests. It would be most helpful to have some idea of the workers manual dexterity and his attitude toward safety prior to employing him for a potentially hazardous position.

Speaking from the standpoint of an engineer and not a physiologist, one cannot help but notice that the uncontrollable movement of a spastic's hands very closely approximates the result one obtains by removing the velocity feedback from a high gain servo system. One wonders what the result would be if accelerometers were placed on the hands and a tactile or auditory feedback as a function of the motion were given to the spastic. The results of velocity feedback are quite remarkable in the case of high gain physical servo system. One can only hazard a guess as to what the results would be when external velocity feedback is coupled to the biological system.

Engineers working in the area of electronic and electromechanical aids for the handicapped should remember that the device should only be sufficiently sophisticated to accomplish the intended purpose. It should be reliable, easy to operate, and safe. Its price should be consistent with the realities of the proposed market.

In conjunction with the price criteria one is forced to conclude that the handicapped people will need external financial aid if they are to be given a chance to reap the rewards of the technological developments.

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